Freshwater Runoff Effects in the Marine Environment: The Gulf of St. Lawrence Example

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April 1982

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1078

Canadian Technical Report of Fisheries and Aquatic Sciences

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CANADIAN TECHNICAL REPORT OF

FISHERIES AND AQUATIC SCIENCES 1078

APRIL 1982

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by

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This is Technical Report Number 83 from the

Marine Ecology Laboratory, Dartmouth, N.S.

Minister of Supply and Services Canada 1981

Cat. No. Fs 97-6/1078 ISSN 0706-6457

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ACKNOWLEDGEMENTS

This report was written at the request of the Atlantic Research Directors Committee of the Department of Fisheries and Oceans. A group was formed, consisting of the authors, under the chairmanship of M.M. Sinclair. The authors were asked to consider the effects of freshwater runoff on the marine environment, including fisheries, in eastern Canada. Special attention was to be given to the large-scale Gulf of St. Lawrence system. The authors were asked to examine physical, chemical and ecological models, along with existing data sets to determine whether evidence exists that freshwater regulation has influenced the marine environment on more than a local scale. We were also asked to determine which parts of the combined physical, chemical and ecological systems need better understanding if runoff effects are to be evaluated. Research programs which could provide this understanding were to be suggested. Ideas expressed in Section 5 of the report reflect the author's opinions of these research needs.

We are grateful to Hans Neu and Bill Sutcliffe who discussed the development of ideas presented in this report and provided access to unpublished data which was used to compile some time series records. F. Jordan, D. Robinson, and G. Ennis also provided unpublished data. Analysis of cod year class strength and environmental variability was carried out with Bill Sutcliffe. H. Neu, B. Petrie, P. Smith, J. Lazier, F. Jordan, and H. Powles read various sections of the manuscript.

ABSTRACT

Bugden, G.L., B.T. Hargrave, M.M. Sinclair, C.L. Tang, J.-C. Therriault and P.A. Yeats. 1981. Freshwater runoff effects in the marine environment: the Gulf of St. Lawrence example. Can. Tech. Rep. Fish. Aquat. Sci. 1078, 88 p.

This report examines physical, chemical and ecological interactions along with existing data sets to determine whether evidence exists that freshwater regulation in the Gulf of St. Lawrence drainage system has influenced the marine environment on more than a local scale.

RÉSUMÉ

Bugden, G.L., B.T. Hargrave, M.M. Sinclair, C.L. Tang, J.-C. Therriault et P.A. Yeats. 1981. Effets des débits d'ean douce le milieu marin: l'exemple du golfe du Saint-Laurent. Can. Tech. Rep. Fish. Aquat. Sci. 1078, 88 p.

Ce rapport examine les interactions physiques, chimiques et écologiques de même les données déjà existantes dans le but de déterminer si la régularisation des cours d'eau du réseau de drainage du golfe du Saint-Laurent a eu une influence plus que locale sur le milieu marin.

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1. INTRODUCTION

"All rivers run into the sea;
Yet the sea is not full" Ec. 1:7

More than water is transferred when rivers empty into the sea. Kinetic and potential energy, dissolved and particulate organic and inorganic compounds and organisms are also exchanged. The effects of these transfers on the receiving waters may be local (direct effects within the plume) or they may arise at a considerable distance from the source of addition of freshwater. While the direct effects of river discharge into the ocean have been documented for physical and biological variables (Revelante and Gilmartin, 1976; Kidd and Sander, 1979), it is not clear how effects propogate over distance. Recent observations, however, show that annual vertebrate and invertebrate fisheries yields or larval survival in coastal waters influenced by freshwater discharge co-vary over time with interannual variation in temperature and runoff (Sutcliffe, 1972, 1973; Skreslet, 1976; Meeter et al., 1979). Mechanisms which link physical and biological processes in marine environments subjected to freshwater input will be considered below; however, correlations imply that non-local effects of runoff do occur. This necessitates that effects of freshwater discharge in an area such as the Gulf of St. Lawrence be considered in as large a geographic context as possible before evidence concerning effects of freshwater regulation is evaluated.

1.1 Patterns of Salinity distribution in the North Atlantic

Wright and Worthington (1970) have calculated the volume of fresh water (as water below 34.4°/$_{oo}$ at temperatures >4°C) in the North Atlantic to be $326.6 \times 10^3 km^3$. Ninety-six percent of this ($315.1 \times 10^3 km^3$) is derived from northern latitudes, principally because of river runoff and excess precipitation over evaporation in the North Polar Sea. Although this volume is minimal (0.2%) relative to that present in the total basin (137.2×10^6 km^3), the non-homogeneous distribution of the fresh water is a major hydrographic feature of the North Atlantic, influencing stratification, transport and mixing processes.

The presence of fresh water discharge around the British Isles, in the North Sea and off the Norwegian coast is evident in the distribution of surface water (30 m) with salinity less than 35°/$_{oo}$ (Fig. 1). This water flows into the North Polar Sea where it is augmented by direct precipitation, river discharge from northern Asia and North America, and input from the Bering Sea (Worthington, 1976). Two current systems converge to transport this low salinity water southward along Canada's east coast. The East Greenland Current flows southward around Cape Farewell to form the West Greenland Current which converges with water moving southward through the Canadian archipelago and then Baffin Bay to form the Labrador Current. Kollmeyer et al. (1966) estimated a flow of 4×10^6 m^3/s in the Labrador Current and more recent studies have confirmed that the magnitude of this transport is generally $5\text{-}6 \times 10^6$ m^3/s (J. Lazier, B.I.O. Dartmouth, N.S., pers. comm.). This southward flow of relatively low salinity water is shallow (upper few hundred meters) but it represents a major feature of the surface circulation of the western North Atlantic Ocean.

Worthington's (1976) review of the distribution of salinity in the North Atlantic shows that it increases in an offshore direction from the North American Coast to the Gulf Stream between Cape Hatteras and the Grand Banks (Fig. 2). There are two distinct increments in salinity, one near the edge of the continental shelf (between Coastal and Slope water) and one at the edge of the Gulf Stream. Within the coastal water, isohaline contours off Nova Scotia and Newfoundland and coastal sea level data (Akenhead et al. 1979) show the presence of fresh water derived from two sources. Low salinity water carried southward by the Labrador Current, which flows around Newfoundland to cover the Grand Banks, extends over the outer regions of the Scotian Shelf and Georges Bank. Water of even lower salinity (<32°/$_{oo}$) derived from the Gulf of St. Lawrence covers the inner portion of the Scotian Shelf. This interpretation is consistent with known or inferred current systems off eastern Canada (Fig. 3). It is complicated by the fact that some of the fresh water from the inshore branch of the Labrador Current enters the Gulf through Cabot and Belle Isle Straits and mixes with Gulf water to form the existing water mass.

The importance of fresh water discharge from the Gulf of St. Lawrence onto the Scotian

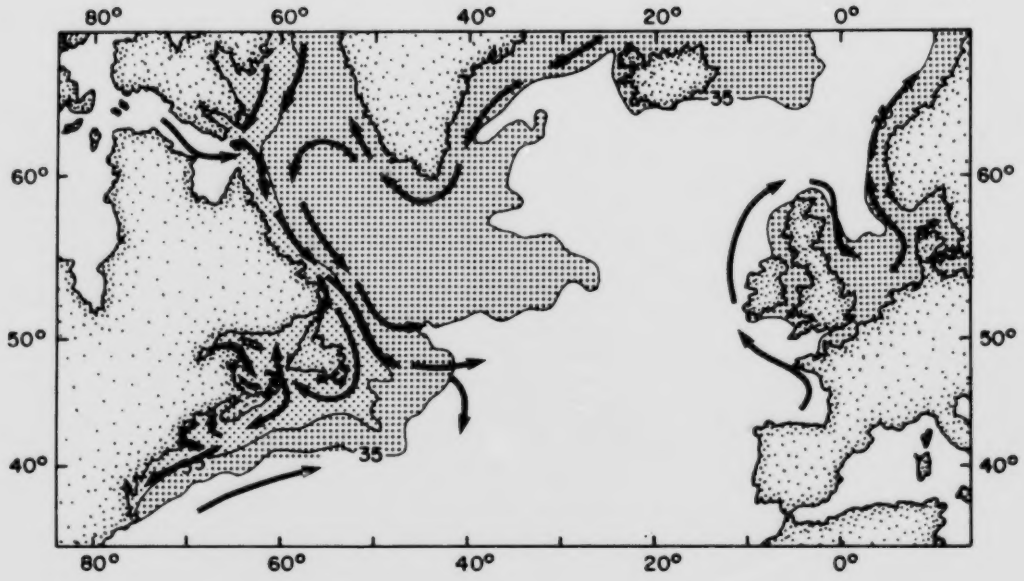


Figure 1 Distribution of salinity at 30 m in the North Atlantic (from Worthington, 1976). Stippled area adjacent to North American continent salinity <33°/₀₀. Other shaded areas salinity <35.0°/₀₀.

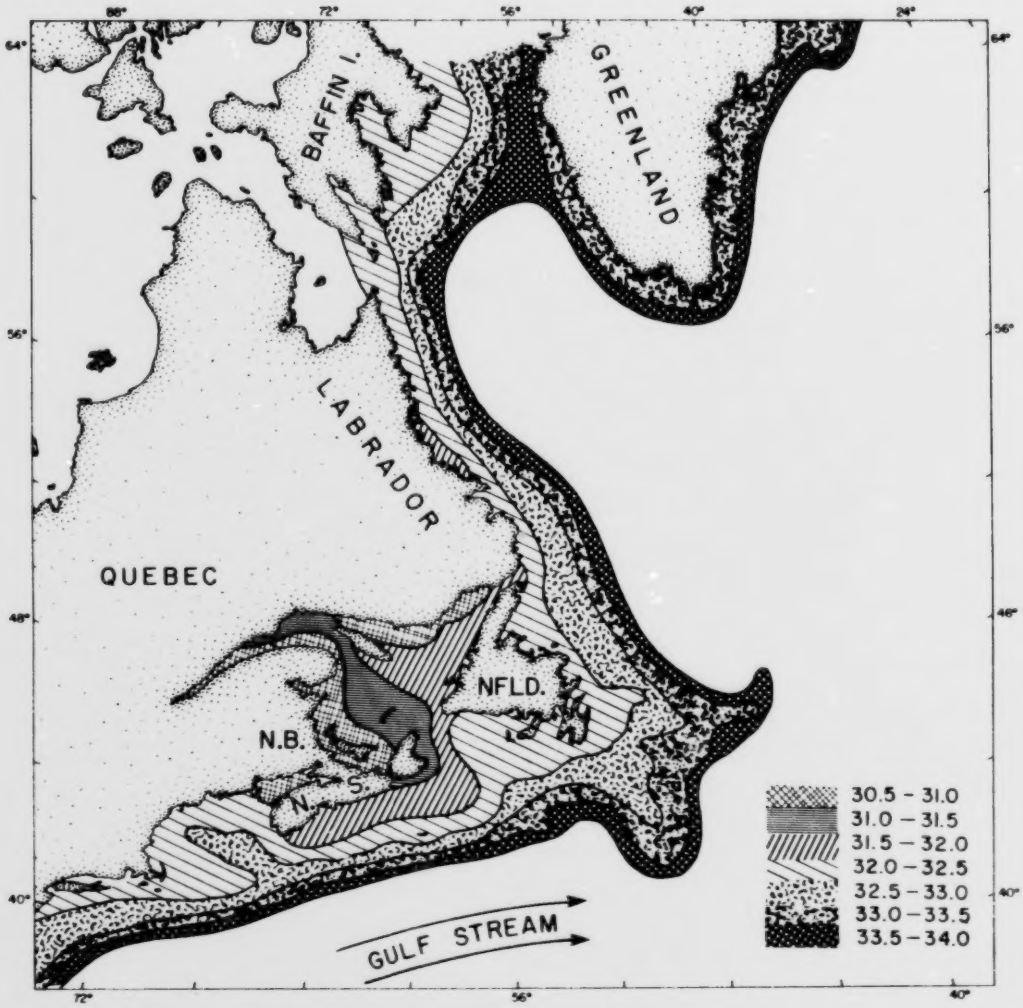


Figure 2 Distribution of salinity at 30 m in the Northwest Atlantic redrawn from Worthington (1976). Salinity in inner part of Gulf of St. Lawrence (St. Lawrence River estuary) 30.5-31.0°/₀₀. Shading indicates progressively higher levels of salinity at 0.5°/₀₀

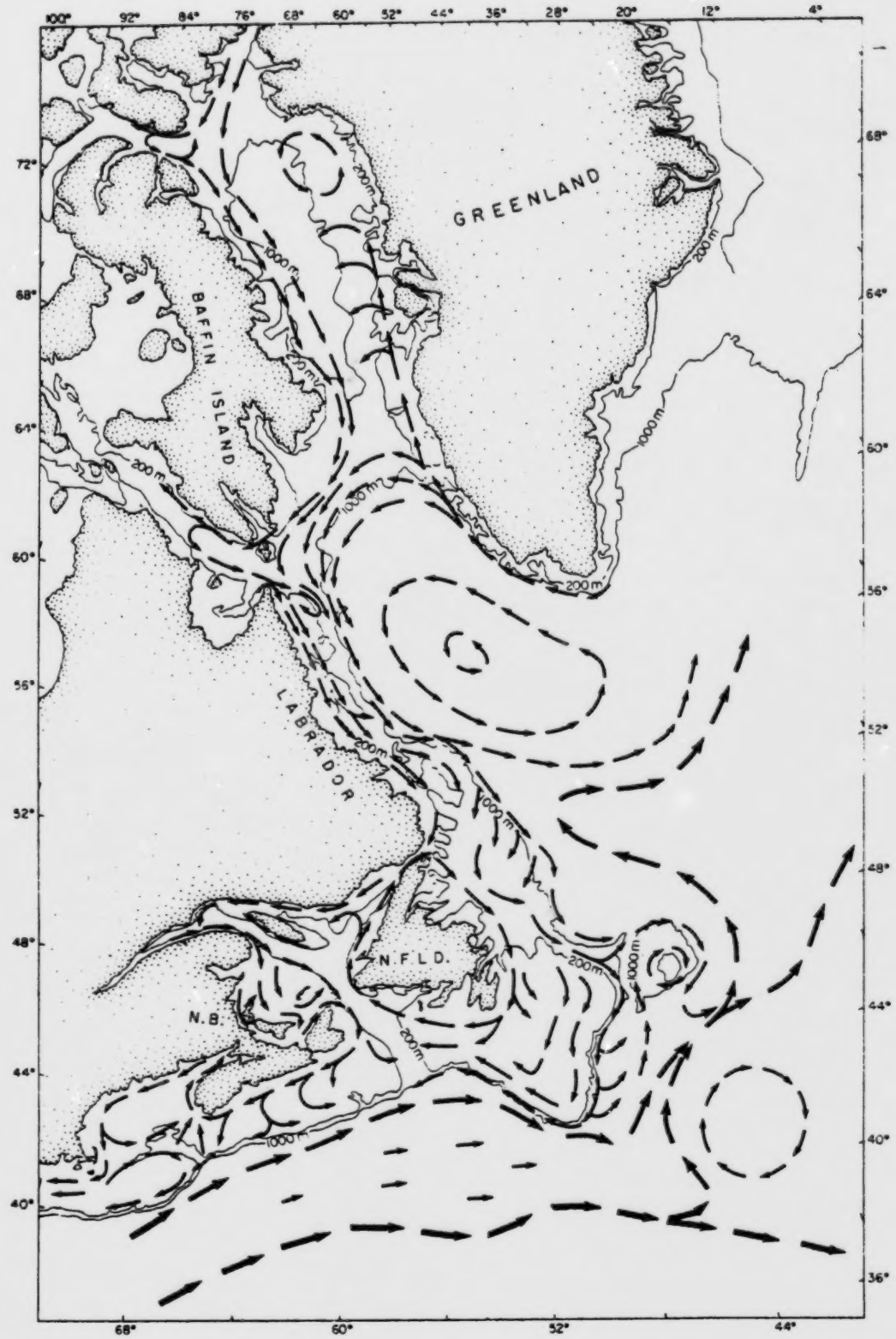


Figure 3 Known and inferred current systems of the Northwest Atlantic (compiled by R. Reiniger and C. Mann).

Continental Shelf and Georges Bank was described by Sutcliffe et al. (1976). Drinkwater et al. (1979) confirmed the magnitude of the effect by calculating that 75% of net annual transport occurred to the southwest over the inshore third of the Scotian Shelf. Estimates of the annual outward transport through Cabot Strait (1.3×10^4 km^3/yr) (El Sabh 1977) and regional variations of the salinity distribution on the shelf (Fig. 2) imply that the source of this water is the Gulf of St. Lawrence (Drinkwater et al. 1979). Houghton et al. (1978) have further demonstrated that strong lateral mixing on the Scotian Shelf leads to a 40% dilution of the Gulf of St. Lawrence water with slope water at Halifax.

1.2 The Relative Magnitude of Annual River Runoff in Eastern Canada

The potential importance of fresh water discharge on oceanic processes can be given perspective if inputs from particular sources are considered relative to the total supply. While discharge rates are monitored in a few large rivers, it has not been possible to estimate accurately runoff from all sources. All calculations are thus degraded by the necessity to extrapolate and to the extent that interannual variation is not considered. Recent calculations of a world water balance (Baumgartner and Reichel 1975), however, provide some useful comparative estimates. By assuming steady-state, estimates of precipitation and evaporation for land and ocean over zones of 5° latitude for the entire earth were derived and balanced. Runoff to oceans was calculated separately and assigned to those 5° latitude zones in which it originated. Annual estimates of inflow from rivers on the North Atlantic east coast (latitude 30-90°N) from Baumgartner and Reichel (1975) are:

Latitude	Km^3/yr	% of total
90-85	-	-
85-80	18	0.8
80-75	69	2.9
75-70	128	5.5
70-65	247	10.5
65-60	165	7.0
60-55	120	5.1
55-50	585	24.9
50-45	660	28.1
45-40	79	3.4
40-35	100	4.3
35-30	176	7.5
Total	2347	100

Of the total annual fresh water runoff, 53% (1245 km^3/yr) occurs between 45° and 55° N. The St. Lawrence river system (with tributaries) discharges 424 km^3/yr into the Gulf of St. Lawrence (Sutcliffe et al. 1976) or 34% of the fresh water input to this 10° zone of latitude. This volume may be compared to El-Sabh's (1977) estimate of annual outward transport of $\approx 1.3 \times 10^4$ km^3/yr through Cabot Strait (giving a ratio of approximately 30 to 1 between St. Lawrence runoff and Gulf of St. Lawrence outflow). Neu (1970, 1975, 1976) concluded from analysis of salinity distributions that the increase in the outflow from the Gulf of St. Lawrence relative to the freshwater runoff is a function of estuarine entrainment. It is also clear that fresh water discharge into the Gulf affects the distribution of fresh water in the coastal regions between 45° and 55°N. As Sutcliffe et al. (1976) point out, annual discharge of the St. Lawrence system alone exceeds fresh water runoff of the entire eastern United States between Canada and Florida. While discharge from the St. Lawrence River itself predominates runoff into the Gulf of St. Lawrence, other rivers contribute substantially to the total annual flow of fresh water into the Gulf as a whole (Table 1). The cumulative discharge of these and other rivers entering from the coasts of Labrador, Newfoundland, Nova Scotia and New Brunswick, maintain coastal salinity gradients which typify the continental shelf ecosystems of eastern Canada.

1.3 Rationale for Considering River-Ocean Interactions in the Gulf of St. Lawrence

The fact that St. Lawrence river system and tributaries constitute a major source of annual freshwater input to the western North Atlantic was discussed above. The magnitude of discharge is such that input of freshwater influences not only oceanographic features of the

TABLE 1. Annual discharge of some rivers in Eastern Canada. All rivers located between 45° and 55°N latitude. St. John and Hamilton Rivers discharge into the Bay of Fundy and North Atlantic respectively. All other rivers flow into the Gulf of St. Lawrence.

River	Discharge km^3/yr	Reference
St. Lawrence (Cornwall)	237	UNESCO (1979)
Saguenay	44	UNESCO (1979)
Aux Outardes	9	UNESCO (1979)
Manicouagan	22	UNESCO (1979)
Moisie	15	UNESCO (1979)
Petit Mécatina	17	UNESCO (1979)
St. John	21	UNESCO (1979)
Hamilton	48	Atlas of Canada (1957)
Rivers discharging along the North shore of the Gulf of St. Lawrence[1]	130	Jordan (1973)

[1] Includes Moisie and Petit Mécatina

Gulf but also contributes to the circulation of the Scotian Shelf and to a lesser degree the Gulf of Maine (Sutcliffe et al. 1976). Mechanisms and effects of river flow on oceanographic processes should be observable in a system of such magnitude, with different physical-chemical-biological interactions arising in different regions.

We must first consider the degree to which the Gulf of St. Lawrence can be viewed as an identifiable ecosystem with recognizable boundaries, before effects of freshwater discharge can be evaluated. It is critical that one considers to what extent, if at all, the variability observed is a function of processes external to the Gulf of St. Lawrence. If fish within the Gulf of St. Lawrence belong to geographically broadly distributed populations along the western Atlantic, then fluctuations in their abundance within the Gulf would not necessarily be a function of internal events. If, however, fish stocks or spawning populations are restricted to the Gulf of St. Lawrence, their temporal fluctuations might be expected to be a function of processes occurring within the Gulf and thus subject to the effects of freshwater runoff control.

Reviews of the physical oceanographic characteristics of the Gulf of St. Lawrence (Trites 1970, 1972 and Trites and Walton, 1973) strongly support the idea that the Gulf forms an integral physical system. The features include an almost entirely local origin of the intermediate cold layer, the restricted exchange of water through Belle Isle Strait, an estimate of residence time on the order of one year and an estuarine type density driven circulation which may permit extensive vertical transport of salt and nutrients. T-S data collected by Jordan and de la Ronde (1974) (Fig. 4) are consistent with earlier observations by Forrester (1964) and Banks (1966) concerning the unique water mass characteristics of the Gulf.

Coote and Yeats (1979) observed that the concentration of nutrients in the deep layer of the Gulf were all approximately three times as high as concentrations at similar depths in the North Atlantic outside the Gulf. They concluded that the Gulf of St. Lawrence traps nutrients resulting from a combination of water circulation and nutrient regeneration processes. Dunbar (1979) summarizes and interprets the oxygen concentration data from the Gulf of St. Lawrence. Observations over several years indicate the presence of an oxygen minimum in the deeper water of the Laurentian Channel, with a marked decrease from Cabot Strait toward the western and northern ends of the Gulf. The reduction in the oxygen content of the deep water in the direction of transport indicates that the water entering through the Cabot Strait penetrates into the Gulf and remains there long enough to be affected by local oxidative processes, including the breakdown of organic detritus and heterotrophic respiration.

Indications of chemical inputs from rivers may be found in the sediments of the Gulf of St. Lawrence. In the Saguenay fjord, high sedimentation rates and lack of bioturbation have permitted radioactive dating of the sediments with resolution of better than one year (Smith and Ellis, 1981). This study has shown that the sedimentation rate is highest under high runoff conditions but metal concentrations are lower at these times.

In the open Gulf of St. Lawrence, lower sedimentation rates preclude this kind of resolution of the geochronology. Thus it is not possible to identify runoff related changes in sediment concentrations in this way. However, several types of chemical measurements in the sediments do indicate the extent of riverborne terrigeneous inputs to the sediments. For example, measurements of the concentrations of lignin and C/N ratio (Pocklington and Leonard 1979) and ^{13}C (Tan and Strain 1979) indicate a significant contribution of terrestrial carbon to the lower St. Lawrence estuary sediments but little evidence of terrestrial carbon in the sediments of the open Gulf.

Steven (1975) and Dunbar (1979) reviewed a large part of the data base on phytoplankton production within the Gulf of St. Lawrence collected as part of the International Biological Program (IBP) study on primary and secondary production in the Gulf. In terms of phytoplankton species composition there are no clear boundaries between the Gulf of St. Lawrence and the contiguous waters. Primary production of the Gulf (including the St. Lawrence estuary) has been reported to be much higher than the "outside" water masses (Dunbar 1979). This relatively higher production has been attributed to the nutrient enrichment processes ("nutrient pump" at the head of the Laurentian Channel, estuarine entrainment, Québec North Shore upwelling and other vertical mixing processes) which transport more nutrients into the estuary and Gulf surface waters than are present in contiguous Atlantic ocean areas. There is some concern, however, about the accuracy of Steven's primary production estimates. Sinclair et al. (1976), and Sévigny et al. (1979) report primary production values an order of magnitude lower than the IBP estimates. Measures of chlorophyll, however, by the two laboratories are comparable.

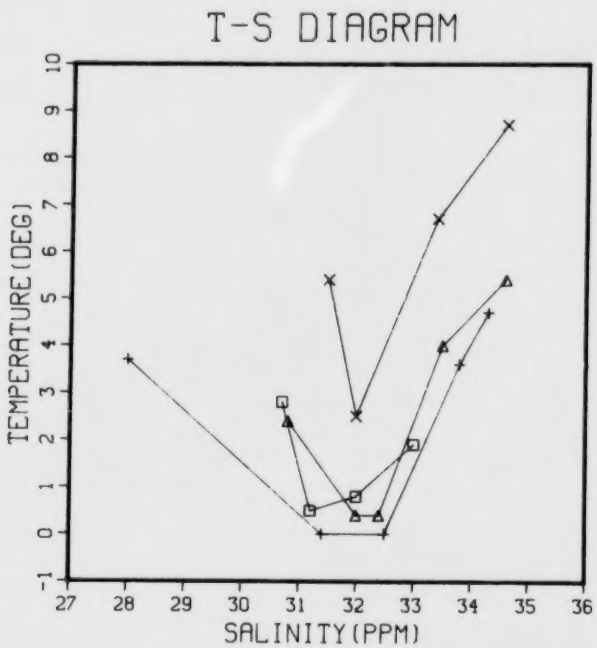


Figure 4 T-S relations for selected stations inside and outside of the Gulf of St. Lawrence. Data are taken from F. Jordan and M.S. De la Ronde (1974).

\+ Gaspé Passage

X Halifax Section

Λ Cabot Strait

Cape Breton Section

Annual measurements of phytoplankton production throughout the year have not been carried out. Measures of daily rates of carbon fixation support the idea that during summer phytoplankton production is enhanced in the region of the Gaspé current in comparison with rates observed on the Scotian Shelf (Table 2). There is very little comparative data outside the Gulf of St. Lawrence (either from the Scotian Shelf or the Grand Banks), and generalizations concerning the relative levels of phytoplankton primary production in the North West Atlantic should be treated with caution.

There does seem to be identifiable differences in zooplankton species composition between the Gulf and contiguous Atlantic waters. West Atlantic continental shelf water at this latitude contains a variety of copepod species but in limited abundance while the Gulf waters contain few species but in greater abundance. Berkes (1976) reports that populations of three euphausiid species out of four in the Gulf were restricted to the Gulf waters. However, zooplankton and benthic macrofauna biomass in the Gulf are not substantially higher on a m^{-2} basis than in adjacent waters (Table 2) as might be expected if the Gulf is a partially isolated system with high phytoplankton production.

There is relatively convincing evidence from fisheries research that a number of important fish stocks complete their life cycle within the Gulf of St. Lawrence and the areas immediately adjacent to the Cabot Strait (4T-Vn Cod, 4RS-3Pn Cod, 4RST Redfish, 4T American Plaice, 4RST Witch, 4T White Hake, Southern Gulf Herring and West Newfoundland Herring). The data supporting the definition of these stocks as being identifiable from those inhabiting adjacent waters comes from a variety of sources (larval distributions, tagging, meristics, morphometrics, etc.). The annual migration movements proposed for Gulf cod (Fig. 5) show that except for overwintering, these stocks complete all phases of their life cycle within the Gulf. There are differences in relative year-class strengths and in some cases timing of spawning between the Gulf stocks and stocks of the same species in adjacent waters. The Gulf herring complex for example spawns throughout the ice free months over a broad geographical area whereas NAFO SA 4-6 herring stocks spawn during restricted periods in late summer-early autumn.The recent good year classes in Gulf herring were in 1966 and 1974; whereas 1970, 1973 and 1976 were strong year classes for herring in stocks in 4WX.

In addition, there are some stocks for which only part of the life cycle and/or annual migration takes place in the Gulf of St. Lawrence (e.g. tuna, mackerel, Greenland halibut). It is believed that a major component of the Western Atlantic mackerel stock spawns within the Gulf, and also that the associated critical early life history phase of the life cycle is completed in this area. In contrast it is felt that the Greenland halibut catches in the Gulf of St. Lawrence, which have only recently become significant, are function of increases in the spawning population off the coast of Labrador.

Biomass trends, as well as fish species composition and their rank order (as shown by the research vessel surveys) are different on the Scotian Shelf and within the southern Gulf (Fig. 6). This provides clear evidence for considering the Gulf of St. Lawrence as an identifiable ecosystem. The year-class strengths of a number of finfish stocks supporting major Canadian fisheries are thought to be determined within the Gulf of St. Lawrence ecosystem and these are not directly related to stocks in the Scotian Shelf.

In summary, from both an oceanographic and fisheries viewpoint, the Gulf of St. Lawrence can be viewed as an identifiable ecosystem. To a large degree one might expect interannual differences in its features to be a function of internal events rather than a result of large scale oceanic processes.

2. HISTORIC DATA FOR EVIDENCE OF EFFECTS OF RUNOFF REGULATION IN THE GULF OF ST. LAWRENCE

If runoff regulation has affected physical, chemical and biological processes within the Gulf of St. Lawrence, these effects will be super-imposed on intra and inter-annual variations arising from natural causes. Thus, it is necessary to describe this variation before attempting to assess the relative importance of possible impacts of runoff regulation.Past observations in the Gulf provide time series records which can be examined for evidence of covariance between variables. This data base, despite variation in duration of observations for different variables, can be used to quantify inter-relationships between variables. The compilation of such information emphasizes the degree of interannual variation and sets limits to our ability to describe 'average' annual cycles. Such a data set also emphasizes existing gaps in

TABLE 2. Comparison of phytoplankton production, zooplankton and benthic biomass in the Gulf of St. Lawrence and on the Scotian Shelf. Numbers in parentheses indicate ±1 S.D.

Variable	Location		Source	Location		Source
Phytoplankton production g C m^{-2} y^{-1}	Mouth of Baie-des-Chaleurs*	212 (62)	Legendre and Watt (1970)			
	Baie-des-Chaleurs*	412 (252)		Scotian Shelf	102	Fournier et al. (1977) Mills (1980)
	St. Georges Bay	172 (29)	Prouse and Hargrave (1979)			
	Eastern Gulf	150	Steven (1975)			
Benthic Macrofauna g dry wt m^{-2}	Central Gulf (86-432 m)	3.5 (1.6)	Hargrave and Peer (1973)	Scotian Shelf (90-180 m)	4.6(1.0)	Mills (1980)(assume dry wt 20% of wet wt)
	Magdalen Shallows (50-77 m)	2.0 (0.8)				
Zooplankton Biomass g dry wt m^{-2}	Central Gulf and estuary (to 50 m depth)	1.2-3.0	Steven (1975)	East of Cabot Strait (to 100 m depth)	2.5	Steven (1975)
	St. Georges Bay (to 34 m depth)	3.1 (1.2)	Harding et al. (1979)	Halifax Section (79-300 m)	2.8 (0.6)	Harding (unpubl.)

* eddy diffusion coefficients, estimated from changes in temperature distribution, used to convert for non-biological changes in dissolved oxygen and phosphate. All other measures of phytoplankton production derived by ^{14}C fixation in *in situ* or light box. Measurements of phytoplankton production during summer and fall months expressed on a monthly average basis and multiplied to give annual estimate.

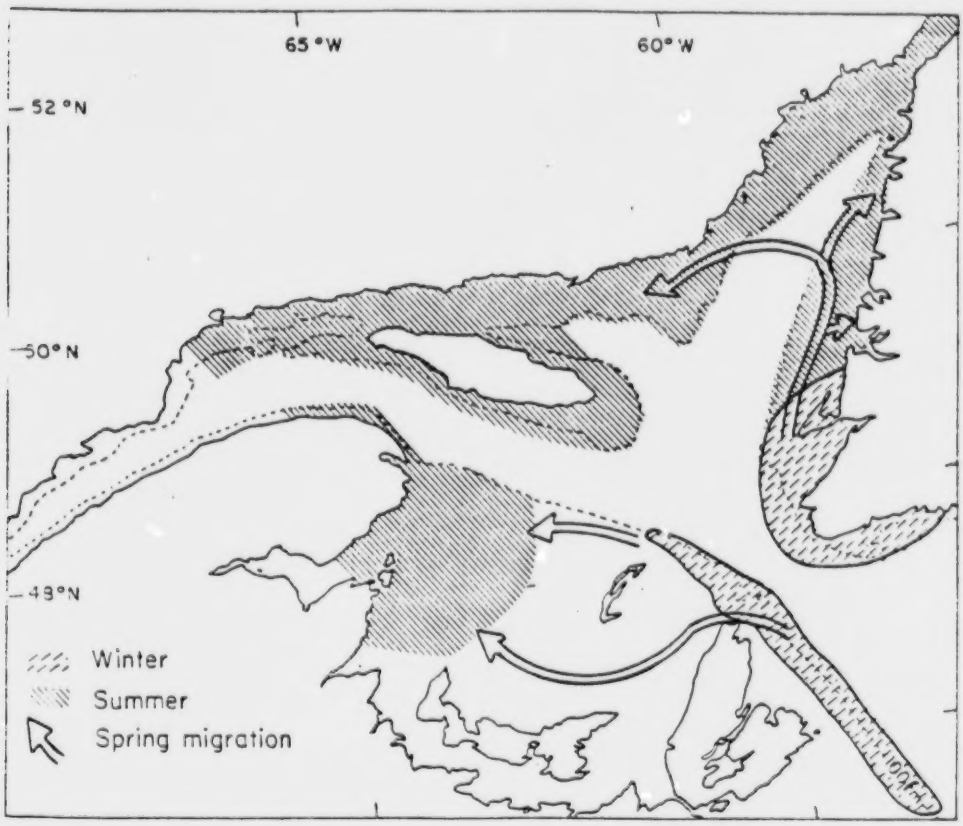
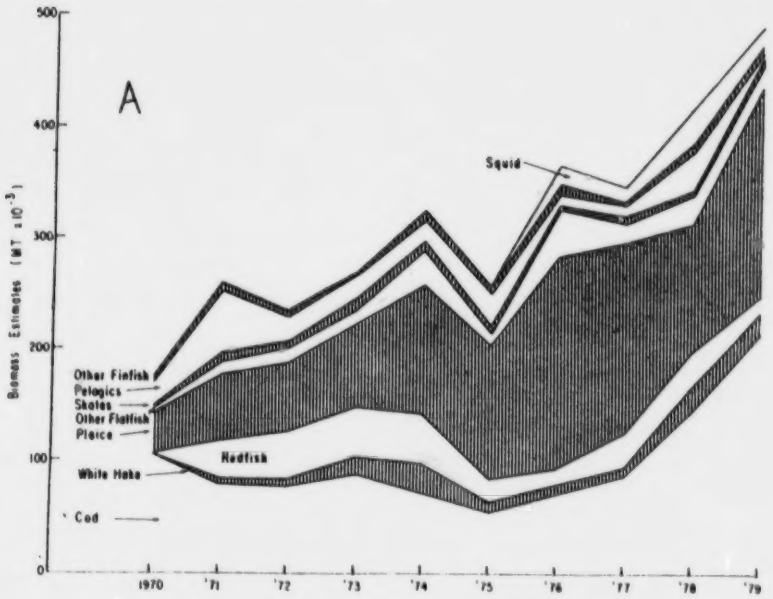
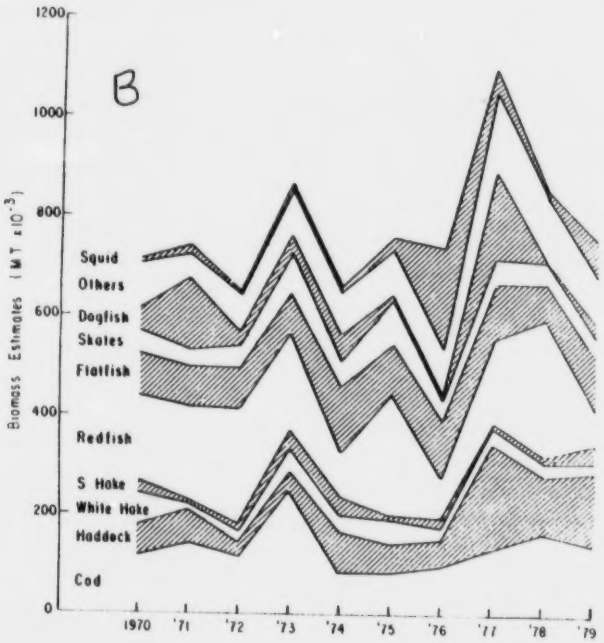


Figure 5 Annual adult migration of the two major Gulf of St. Lawrence cod stocks (Halliday and Pinhorn 1980).



Survey biomass estimates - Gulf of St. Lawrence.



Survey biomass estimates - Scotian Shelf.

Figure 6 **Annual estimates of stock biomass for fish populations in (A) the southern Gulf of St. Lawrence and on (B) the Scotian Shelf (Herring not included) (Koeller 1980).**

knowledge which limit conclusions concerning effects of runoff regulation on properties of the ecosystem.

2.1 Historic Changes in Reservoir Capacity

There have been dramatic changes in freshwater storage with the St. Lawrence River and Gulf of St. Lawrence drainage basins during the past two decades (Fig. 7). The data illustrate the increase in reservoir capacity due to dam construction since 1908. At present, this amounts to approximately 70 km^3 while the annual discharge of the St. Lawrence River and tributaries into the Gulf is 424 km^3 (Sutcliffe *et al.* 1976). While storage itself does not alter total annual discharge, the important effect of runoff control is the displacement of discharge from the spring to winter months as discussed below. The shape of the curve, however, indicates that if freshwater discharge regulation has had observable environmental effects, superimposed on natural variations, these effects should be greatest over the last decade when the volume of storage capacity approximately doubled.

2.2 Physical Variables

2.2.1 River Discharge and Water Level Data

Of all the marine environmental data collected in modern time, river discharge and water level data are probably the most extensive in coverage and longest in time. Observations began in the early years of the century and have continued without interruption to the present. The gauging stations are distributed over the entire drainage area and around the coast of the St. Lawrence system. The data are published periodically in government publication series and are thus easily accessible. The interest in river discharge and water level is apparently derived from the need for such information for hydroelectric development and navigation purposes. The discharge data have been used by Jordan (1973) and Neu (1975) to demonstrate the effect of runoff regulation on the fresh water transport through several sections in the St. Lawrence River and Estuary.

A distinctive feature of this data set is, unlike oceanographic data, its year-round coverage. There are occasional gaps and the presence of ice at some stations during the winter months could affect the stage-discharge relation, thus introducing some errors in the data. The river discharge and water level records, however, represent a fairly complete data set and contain a wealth of information. A direct analysis without invoking any underlying dynamical assumptions can give us seasonal and inter-annual variations of the fresh water transport through a given section in the estuary, with and without runoff regulation.

The major source of fresh water in the St. Lawrence Estuary and the Gulf of St. Lawrence is the St. Lawrence River and rivers on the north shore of the Gulf (Fig. 8). Most of the large rivers in the drainage area of the St. Lawrence system are guaged. The guaging stations number over four hundred and are operated by either the Québec or the federal government. The discharge records are obtained by two types of gauges. The recording gauge gives a continuous record of water level on a graphical chart from which discharge rates are computed from the state-discharge relation (the relation between the water level and the discharge). The manual gauge is non-recording and one or more readings per day are taken manually. The data collected at the hydrometric stations have been published annually since 1908 in various government publications. The source data for Québec are summarized in Appendix I.

Jordan (1973) computed the natural and regulated fresh water transport at Pointe-des-Monts using all the available discharge and storage records in the St. Lawrence drainage basin (Fig. 9). It can be seen that in the summer the peak discharge is reduced by 15-35% due to regulation. The calculations do not take into account the travel time of the fresh water from the river mouth to Pointe-des-Monts. Thus the actual reduction is expected to be less and the peaks are expected to be broader than those shown in Fig. 9. The freshwater runoff into the Saguenay Fjord since the turn of the century is shown in Fig. 10. There is a stepwise reduction in the seasonal amplitude in parallel with the increasing regulation indicated in Fig. 7.

The freezing and melting of sea ice must also be considered as the formation of ice removes freshwater from the water column and the subsequent melting releases it again. Although the annual total discharge from this process is zero if advection of ice can be neglected, the

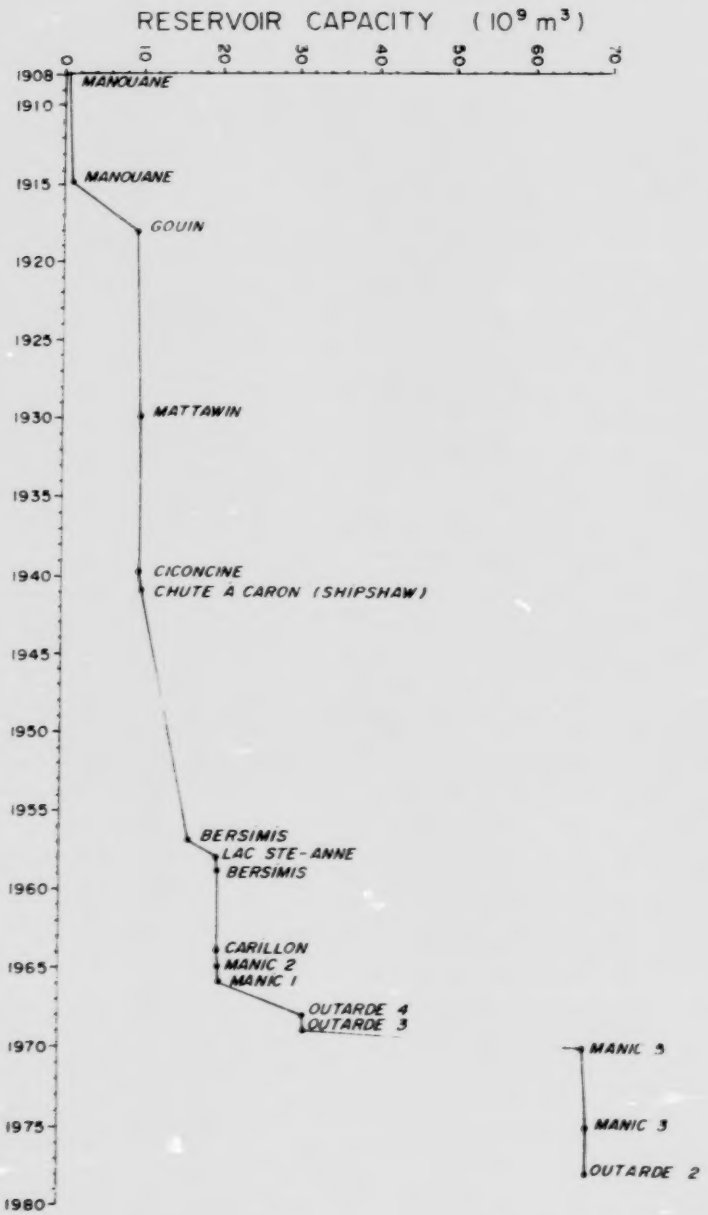


Figure 7 Historic changes in reservior capacity within the St. Lawrence River drainage system. (Compiled by J.-C. Therriault).

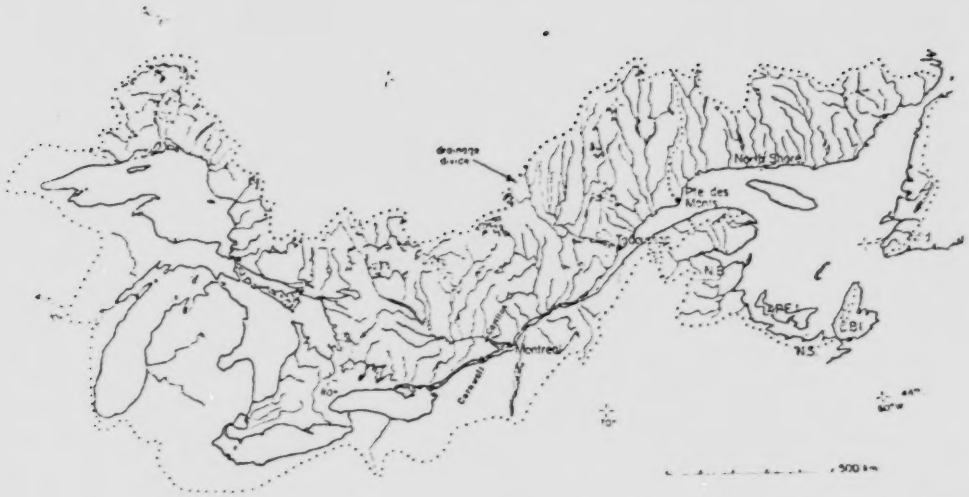


Figure 8 Drainage Area for the St. Lawrence River System

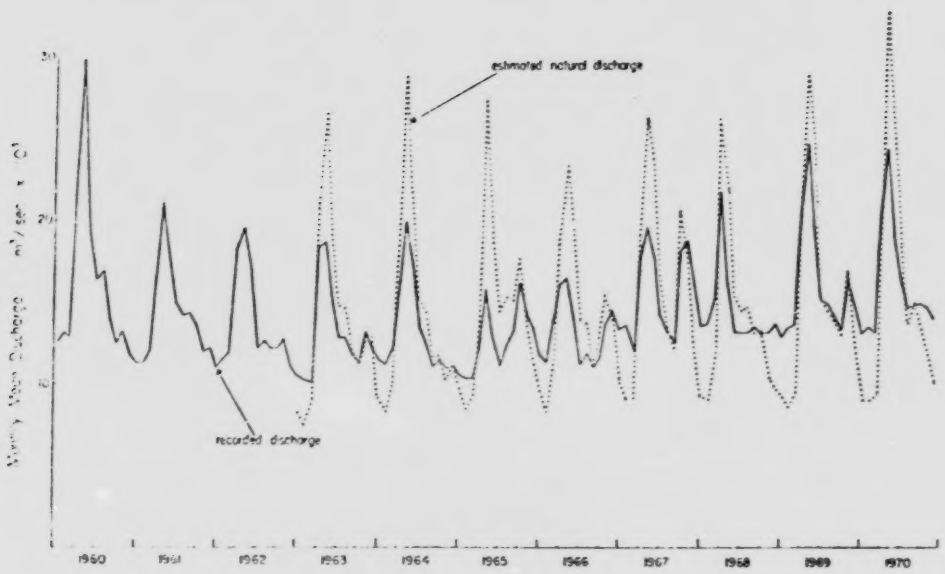


Figure 9 Runoff for the St. Lawrence System at Pointe-des-Monts (from Jordan 1973).

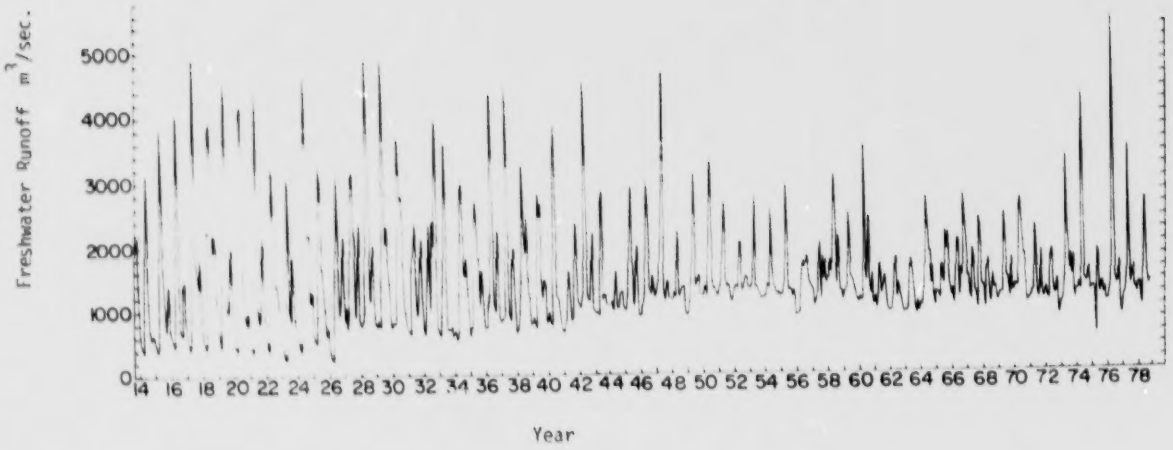


Figure 10 Discharge from Saguenay River (monthly means) between 1914 and 1978 (compiled by J.N. Smith, BIO). Changes in discharge pattern are apparent after 1926 (Ilse-Maligne power plant installed) and 1942 (Shipshaw power plant installed).

equivalent discharge is at times significant. Using data given by Forrester and Vandall (1968) the discharge implied by ice freezing reaches $-8 \times 10^3 m^3/s$ in mid-February and the same magnitude but positive in mid-April. An examination of Figure 9 reveals that this is a significant effect.

Sutcliffe (1973 and pers. comm.) has also compiled historical data for river discharge from the St. Lawrence and major tributaries (the Ottawa and Saguenay Rivers) (RIVSUM). These data (Appendix II, Fig. 11 a-d) constitute monthly and annual time series records which directly represent variations in the major source of freshwater discharged into the Gulf of St. Lawrence (Table 1). Monthly average values for RIVSUM are maximum during May and June (Fig. 11b) with lowest and intermediate values during September/October (Fig. 11c) and January/February (Fig. 11d) respectively.

Some evaluation of interannual variation can be calculated from the river discharge data. The coefficient of variation (standard deviation/mean) of RIVSUM annual mean runoff (1950 to 1979) which is not influenced by regulation is only 10%. The maximum level observed in 1974 is ~50% higher than the minimum in 1963. The impact of modification in the seasonal runoff pattern (as shown in Fig. 9) has to be considered in relation to the above level of interannual variability.

Water level data are collected by the Canadian Hydrographic Service and the Water Survey of Canada under the direction of the Chief, Tides, Currents and Water Level, Canadian Hydrographic Service. Processing of the data is carried out by the Marine Environmental Data Service Branch of the Department of Fisheries and Oceans. The data are published annually in two series titled, "Water Levels, Tidal Highs and Lows" and "Water Level, Daily Means". The former gives the time and heights of high and low waters as recorded daily at permanent gauge locations. The latter contains the daily, monthly and yearly mean levels and the extreme levels from each month. The daily and monthly means are computed from hourly readings, and the yearly means are the average of the daily means.

In the St. Lawrence system, there are at present 16 permanent gauging stations from Montreal to Pointe-des-Monts, and 10 around the coast of the Gulf of St. Lawrence. The locations of these stations are shown in Fig. 12. The majority of the water level gauges are float operated, but some are pressure actuated. Most of them record in analog form on a continuous strip chart, but some record in digital form on punched paper tape at fixed time intervals, usually 15 minutes.

In order to obtain useful information about the physical processes relevant to environmental studies, the discharge and water level data should be used in conjunction with other oceanographic data such as currents, temperature and salinity. In the absence of long time series of the latter, any attempt to extract information from the discharge and water level data alone would inevitably involve dynamical assumptions not easy to verify. Here we show a few selected time series and a simple analysis to give the readers some indication of the gross features, the potential and limitations of the data set.

Fig. 13 shows the yearly mean water level from 1962 to 1977 at 7 stations. Even though the mean transport of fresh water at Pointe-des-Monts (unpublished and revised calculation by F. Jordan) (Fig. 14) is correlated with the water level data at Québec City ($r = 0.93$) there is no clear relationship between annual mean water level and freshwater discharge at other stations at increasing distances from Québec. There is also similar year to year variation illustrated in annual mean RIVSIM estimates (Fig. 11). This indicates that the annual variation in the fresh water runoff is reflected in the water level record at Québec City, but not at the other places.

Fig. 15 shows the monthly mean water level averaged over many years. The general pattern is high water level during the summer months, and a minimum in the fall. Such seasonal variations are present in all the records. To obtain information about the current, we assumed a geostrophic relationship (Garrett and Petrie 1981) between the surface current and the water level difference across the estuary and calculated the difference year by year for two pairs: Rivière-du-Loup/Tadoussac and Pointe-au-Père/Baie-Comeau. The results are shown in Figs. 16a and 16b. There is no apparent correlation or pattern in the results. A comparison of Fig. 14 and 16a,b suggests that the runoff does not seem to have obvious effects on the average surface current. It is more likely that other factors such as wind stress have a greater influence on the surface current.

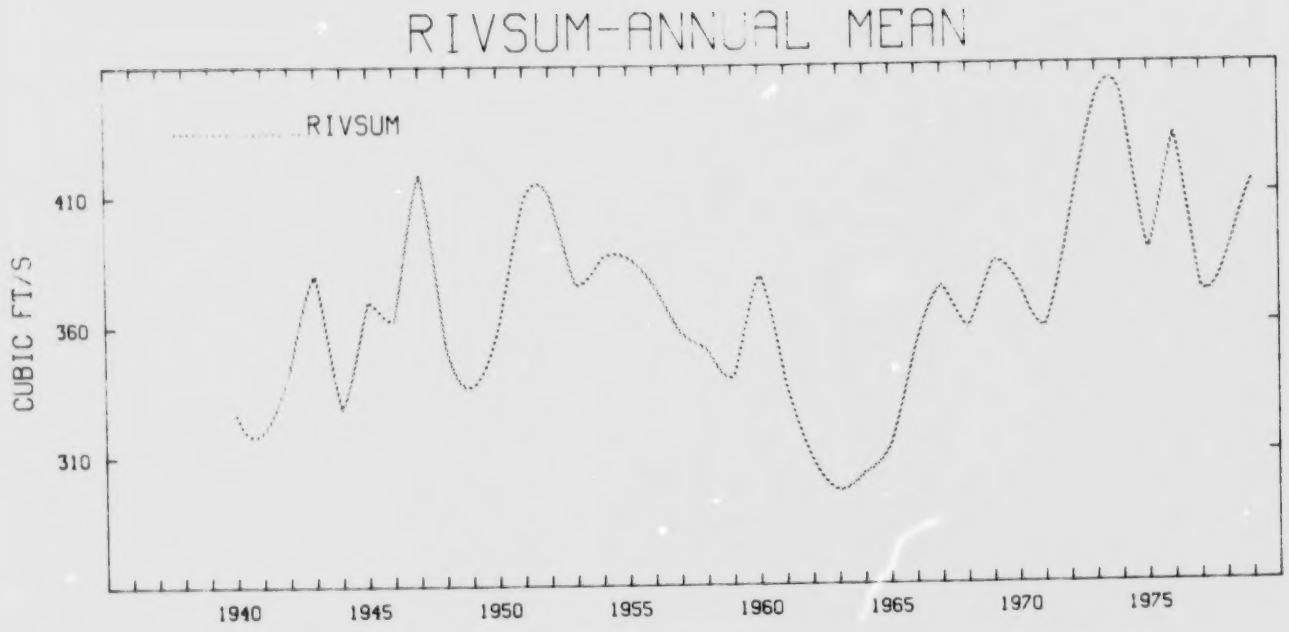
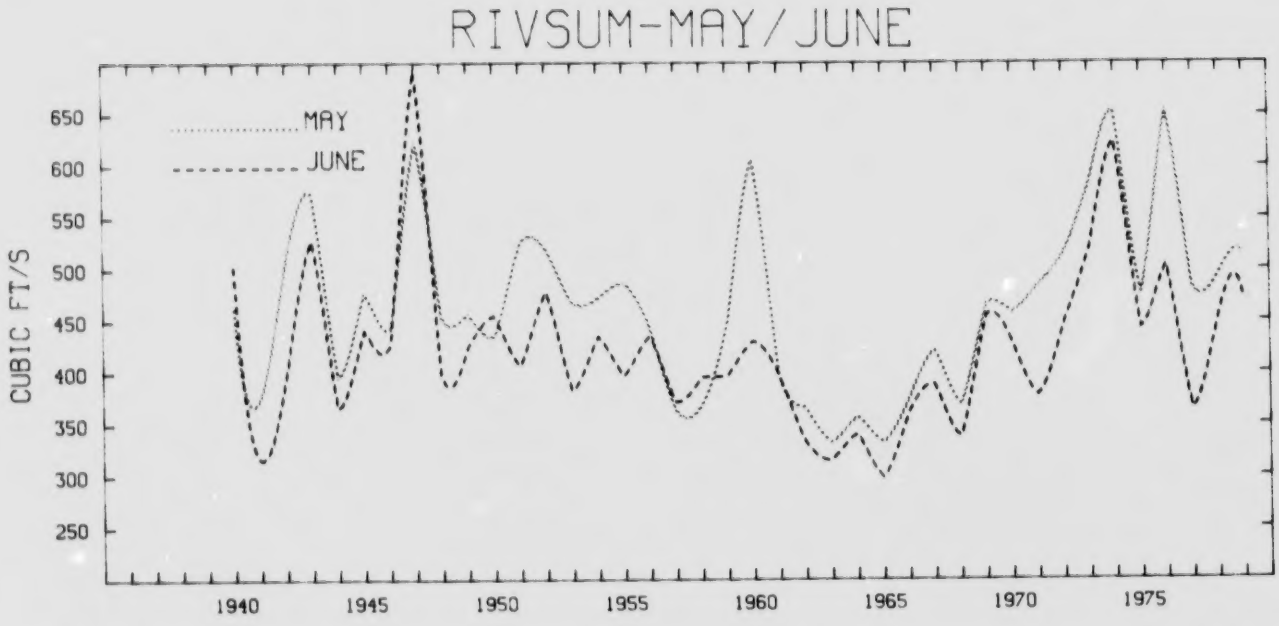
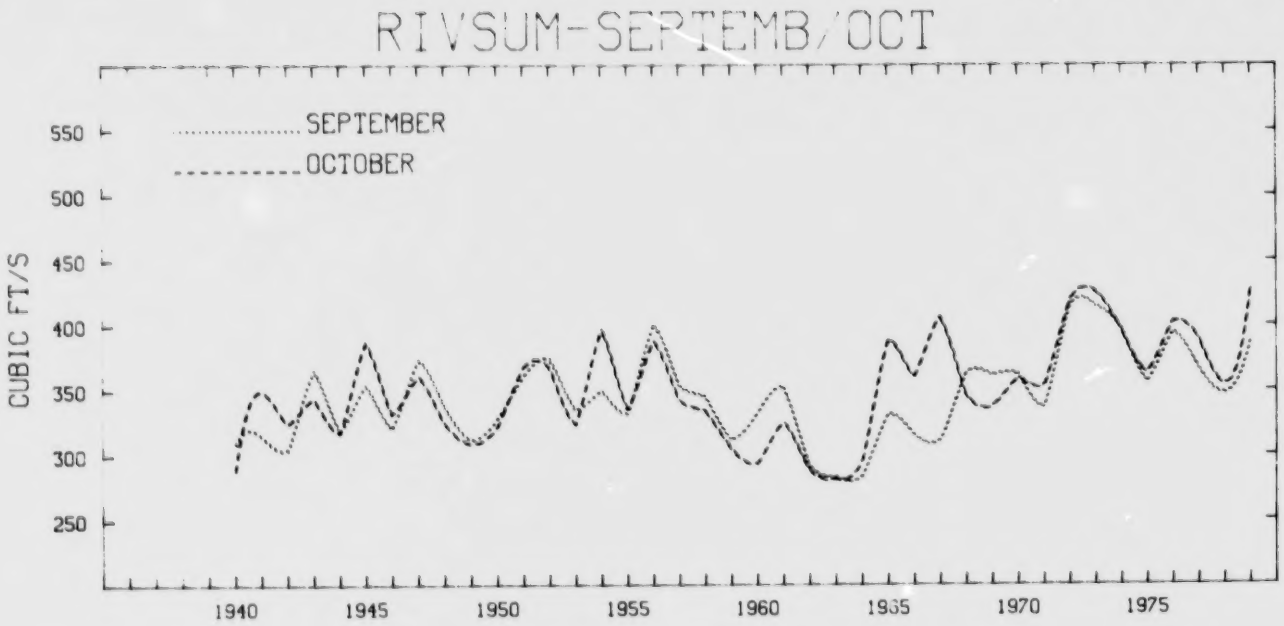
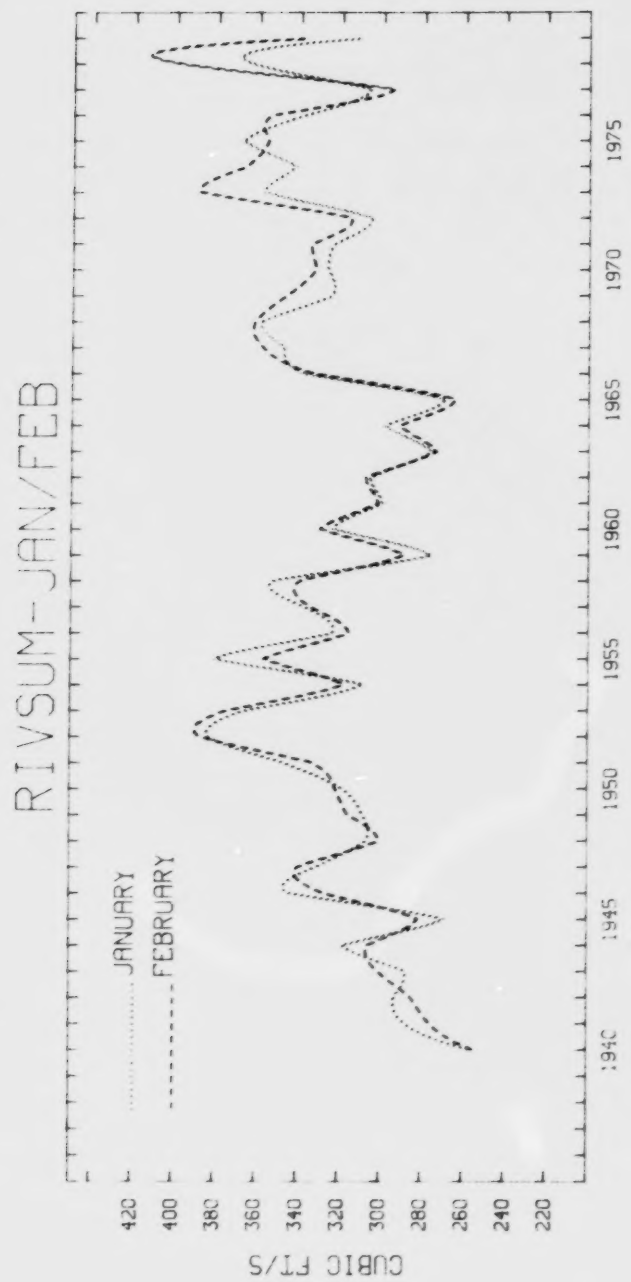


Figure 11 a-d Annual and monthly average river discharge from the St. Lawrence River (at Cornwall) and from the Ottawa and Saguenay Rivers. Data from Appendix II taken as individual data points for each year drawn by a plotting routine.


RIVSUM-MAY/JUNE
MAY
JUNE
CUBIC FT/S
650
600
550
500
450
400
350
300
250
1940
1945
1950
1955
1960
1965
1970
1975


RIVSUM-SEPTEMB/OCT
SEPTEMBER
OCTOBER
CUBIC FT/S
550
500
450
400
350
300
250
1940
1945
1950
1955
1960
1965
1970
1975


RIVSUM-JAN/FEB
JANUARY
FEBRUARY
CUBIC FT/S
420
400
380
360
340
320
300
280
260
240
220
1940
1945
1950
1955
1960
1965
1970
1975

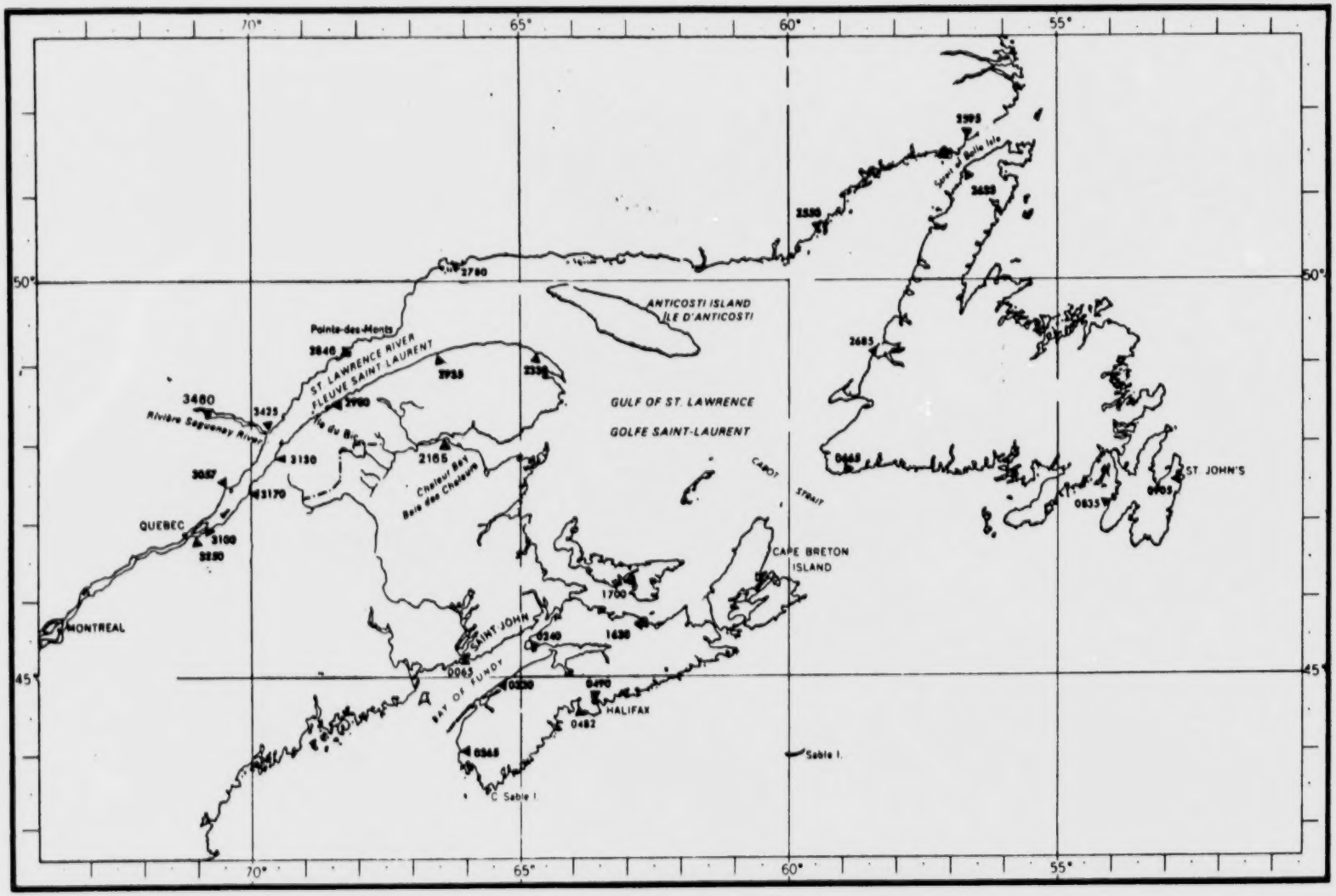


Figure 12. Locations of permanent tide gauging stations.

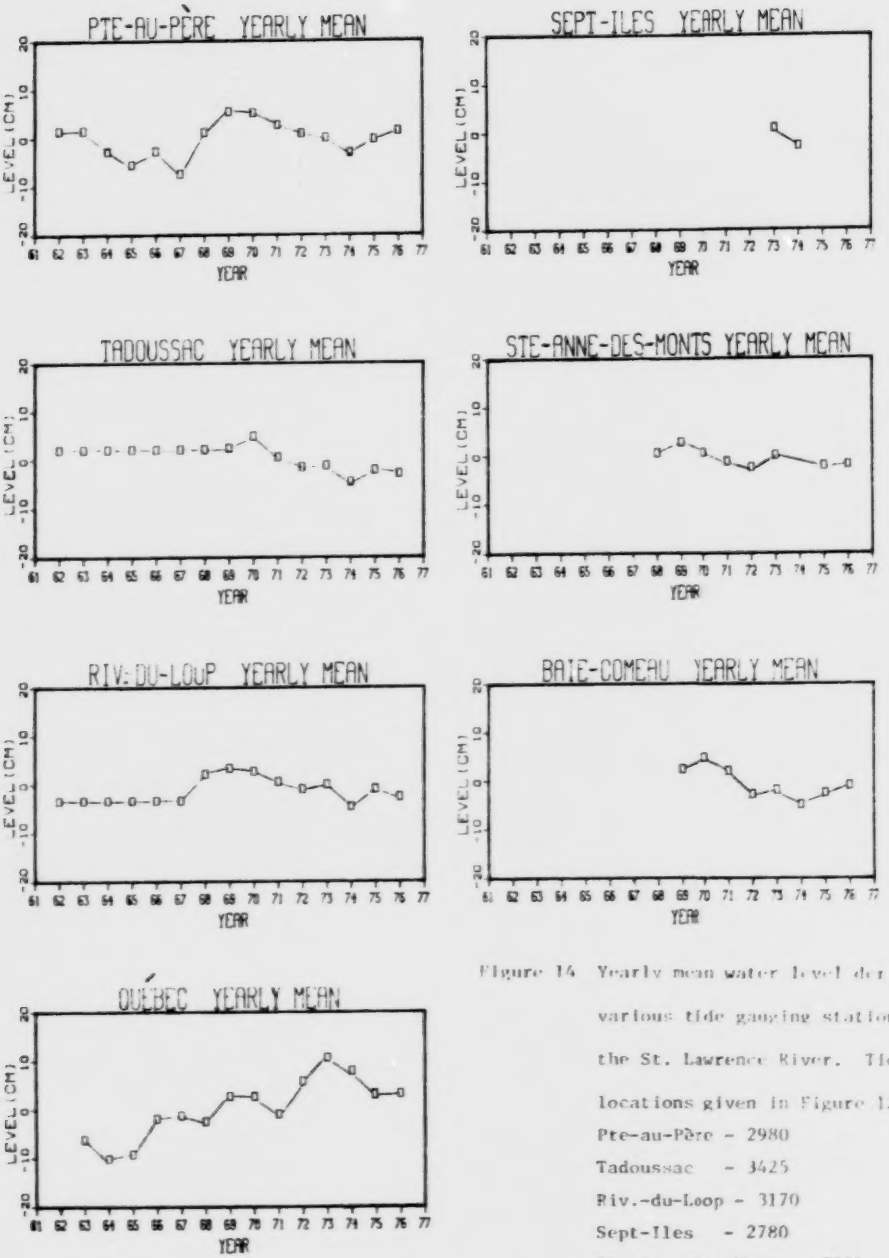


Figure 14 Yearly mean water level derived from various tide gauging stations along the St. Lawrence River. Tide gauge locations given in Figure 12:

Pte-au-Père - 2980

Tadoussac - 3425

Riv.-du-Loop - 3170

Sept-Iles - 2780

Ste-Anne-Des-Monts - 2935

Baie-Comeau - 2840

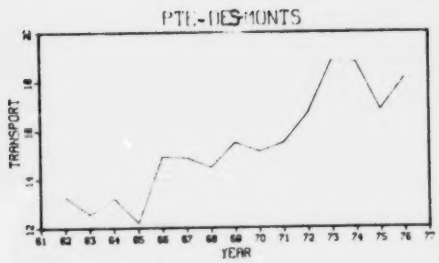


Figure 14 Fresh water transport in 10^3 m^3/sec at Pointe-des-Monts (Unpublished calculations from F. Jordan, B.I.O., Dartmouth, Nova Scotia, pers. comm.).

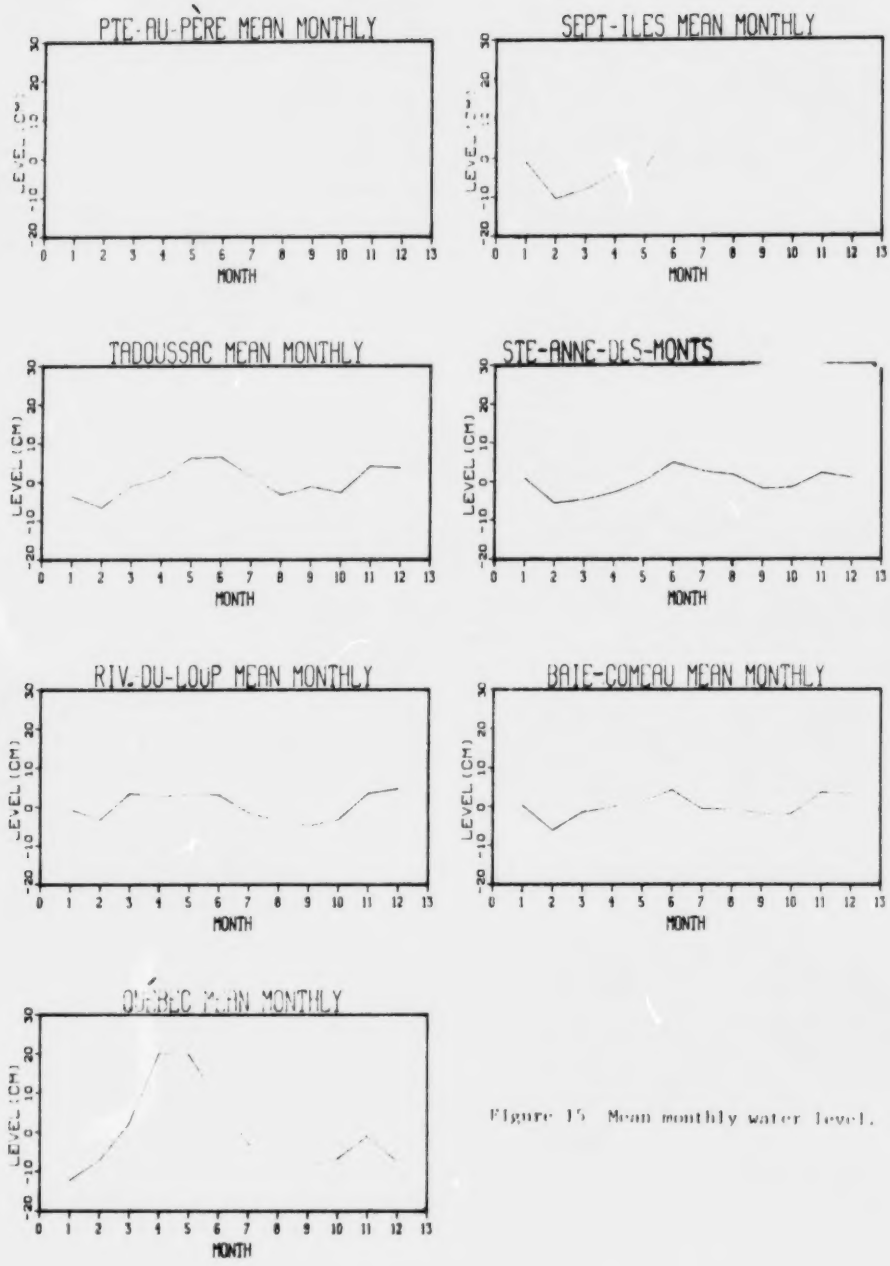


Figure 15 Mean monthly water level.

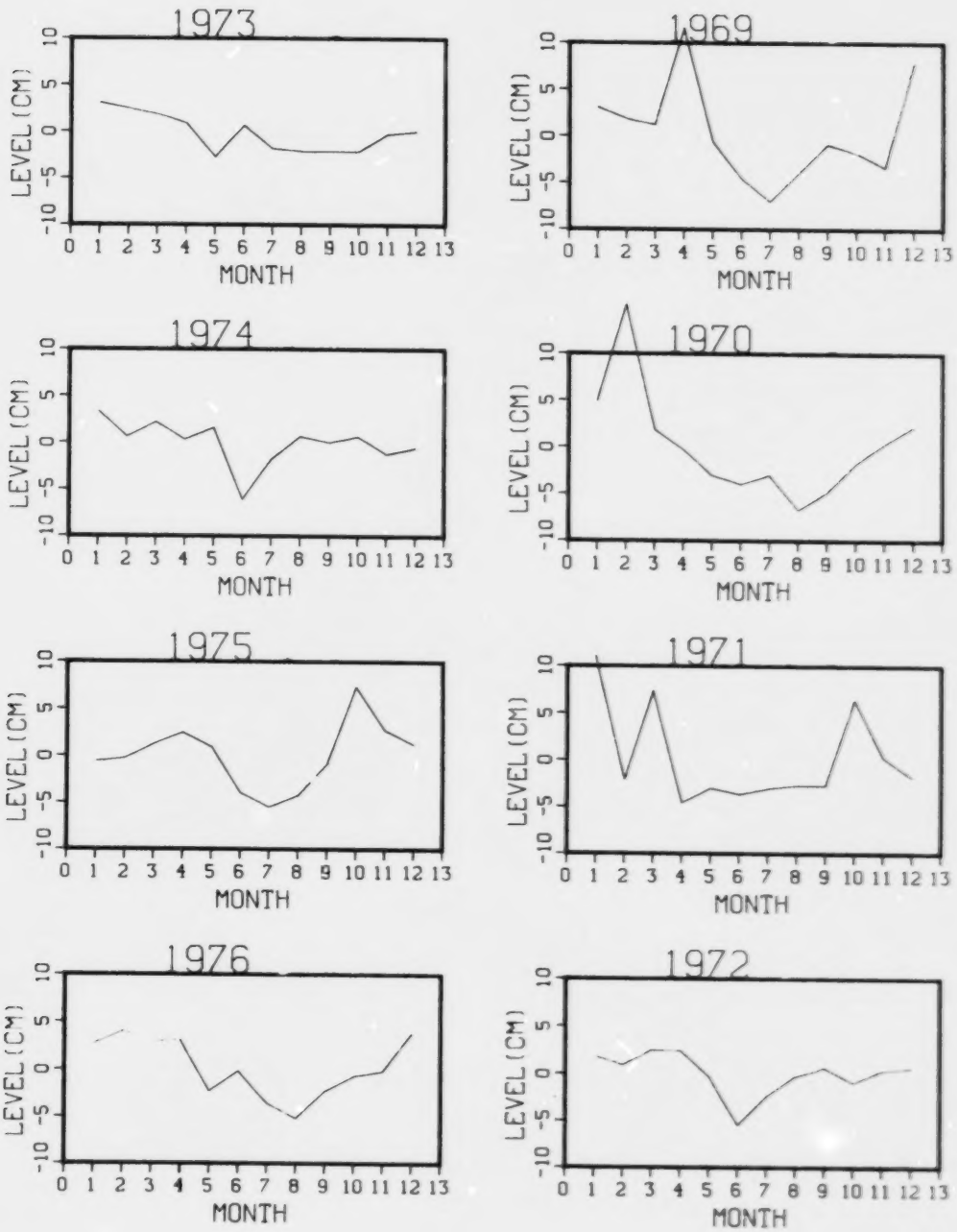


Figure 16a Difference in water level between Rivière-du-Loup and Tadoussac.

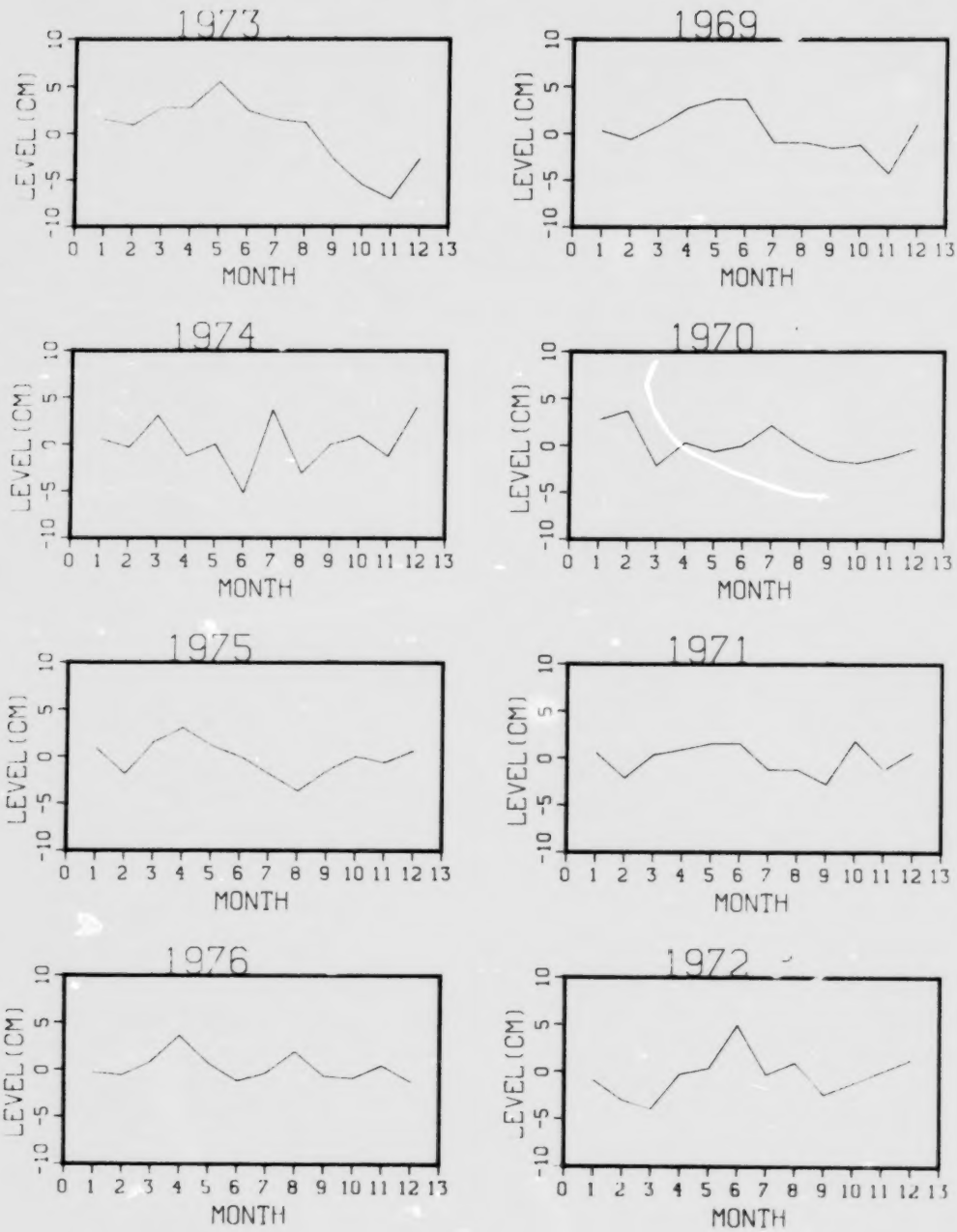


Figure 16b Difference in water level between Pointe-au-Père and Baie-Comeau.

2.2.2 Water Temperature

Water temperature data for the Gulf of St. Lawrence are available from several sources in forms suitable for the examination of year to year changes. The Marine Environmental Data Service (MEDS) in Ottawa maintains computer files of bathythermograph, reversing thermometer and CTD data indexed by geographic region. Surface water temperatures from various shore stations are also available. For the purposes of this report, the Gulf was divided into 3 regions: the Magdalen Shallows, the North-East Gulf and the North-West Gulf. The average temperature over the top 10 metres was compiled on a monthly basis for each of the three regions from the bottle and bathythermograph data, the CTD data file being as yet incomplete. These data are summarized in Appendix II for comparison with surface temperature observations from shore stations and to examine the relationship between the three regions and other compiled variables.

The average temperature over the top 10 metres of the water column was felt to represent the temperature of the surface mixed layer adequately for this study. Attempts to define the characteristics of the surface layer in more detail met with technical difficulties beyond the scope of this report. Data quality and quantity was deemed sufficient to supply values from 1944-1977 for the months May to November only and numerous gaps exist within these limits. The standard error in the individual values is estimated to be about ±0.3°C. This surface layer data should be sufficient to at least indicate the magnitude of climatic variations expected and perhaps to examine the relative importance of various factors controlling the physical characteristics of the mixed layer such as buoyancy flux and wind mixing.

Simple linear correlations between the temperatures of the three Gulf regions and the two shore stations, Grande-Rivière and Entry Island indicated that in the spring, temperatures in the North Eastern Gulf were almost unrelated to the others. Correlation coefficients (r) were generally 0.5 to 0.6 between the shore stations and among the other regions for the month of June which was chosen as typical for spring. For the month of August, the correlations were lower with the North Eastern Gulf exhibiting some negative relationships with other regions. The highest correlation for August was between Entry Island and the Magdalen Shallows as might be expected. In the month of November, all the temperature values were uniformly highly correlated ranging from 0.7 to 0.9. This simple analysis implies that during the spring and summer, near surface temperatures in the Gulf are perhaps partly determined by the unequal distribution of fresh water which is confined primarily to the southern and western Gulf. During the fall surface cooling on a Gulf-wide basis seems to be the dominant factor. Further detailed work is needed to elucidate these points.

Several parameters characterizing the interannual variations in the intermediate cold layer, a striking characteristic of the waters of the Gulf of St. Lawrence, were also compiled from the BT data. These parameters were taken from that part of the Gulf which is deeper than 200 m. All parameters were interpolated to the middle of July for their respective years. Values for the depth of the temperature minimum, the value of the temperature minimum and the upper and lower depths of the 1.5°C isotherms (considered to be the bounds of the intermediate water) were compiled for the years 1951 to 1975 and are summarized in Appendix II. These data may be useful in determining which factors control winter-time convection and ice formation and to what degree. Standard errors on the various depths are estimated to be less than ±10 m and that for the temperature ±0.3°C.

2.2.3 Meterological Variables

Meteorological variables such as air temperature, solar radiation, humidity and wind speed are available from the Atmospheric Environment Service for many observing stations scattered around the Gulf. One of the most valuable of these stations is Grindstone Island which because of its island location in the southern Gulf is probably representative of over-water conditions in this area. Other stations will suffer from windward-leeward coast effects, geographic wind distortion, and so on. In general, meteorological data are much more complete and extensive than physical oceanographic or biological data. Monthly mean air temperature data as well as some limited wind data from Grindstone Island are reproduced in Appendix II. Direct measurements of solar radiation from Kentville, N.S. are also presented in Appendix II as measurements in Charlottetown, P.E.I., the closest station to the southern Gulf which regularly performs this measurement began only in 1970. A linear correlation of monthly average values between 1970 and 1979 at Kentville and Charlottetown produced a slope value of 0.97 and an r^2 value of 0.98. Thus it is assumed that amounts of radiation received at Kentville are equivalent to those received throughout the region generally.

2.2.4 Ice Cover

Ice cover information is available for the Gulf of St. Lawrence from the Atmospheric Environment Service which conducts periodic air surveys during the ice season. The observations from these surveys are combined with available ship, shore and satellite observations to produce weekly ice summary charts. Complete charts are available from 1962 to the present. Various hatched line patterns and number codes are used on these charts to indicate the ice concentration and type. Unfortunately, in this form the data are largely qualitative, numerical calculations and comparisons requiring extensive digitizing effort. Forrester and Vandall (1968) made a first effort in this direction, evaluating ice volumes for 10 regions of the Gulf at bi-weekly intervals for the years 1962 to 1967.

2.3 Chemical Variables

2.3.1 Salinity

Salinity data for the Gulf of St. Lawrence suitable for this study are available from MEDS as computer archived bottle data, and some limited shore station data is also available. The data from the MEDS files were treated in the same manner as the temperature data described previously. Averages were formed for the top 10 metres for 3 regions of the Gulf. Unfortunately, these data are not of nearly as high quality as the temperature data for several reasons. Salinity is much more difficult to measure accurately than temperature, so data quality vary depending upon the operator and method. Also, the factor which largely controls the salinity of the surface waters of the Gulf, the discharge of the various rivers around the perimeter, is by nature a point source of perturbation. This leads to large horizontal gradients which are not in general resolved by the sampling density, introducing large uncertainties in the regional averages. Vertical resolution is also inadequate as only discrete bottle samples provide a sufficiently long time series for examination as opposed to the continuous vertical profile information provided for temperature by the bathythermograph data. Data are reproduced in Appendix II.

2.3.2 Dissolved Inorganic Nutrients

A limited set of nutrient data (nitrate, phosphate and silicate) covering the years 1969-1975 exists for the Gulf of St. Lawrence. These samples were collected throughout the Gulf, generally between April and September, by two different groups; the McGill University IBP study (Steven 1975) covers the years 1969-1972, and BIO Chemical Oceanography cruises between 1971 and 1975. While the quality of the data from each group's first year of study is not as good as subsequent year's results, there is reasonable agreement between the two studies for the remaining years, although the McGill data shows more scatter.

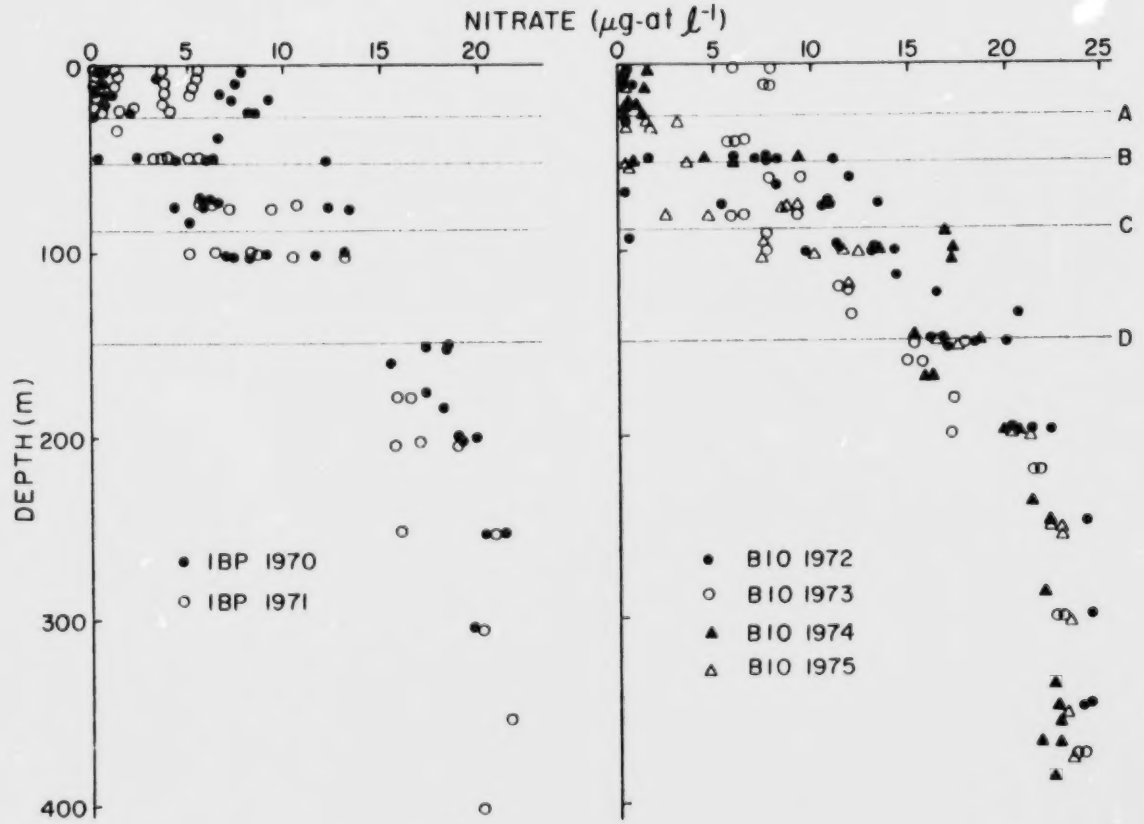
The geographic and temporal coverage of the McGill data is better than that of BIO. The McGill study includes 226 stations. Although many were occupied as often as six times a year as well as frequently sampled shore stations, most samples were taken from shallow depths (upper 50 m). The BIO measurements were made on one to three cruises to the Gulf during any one year following sometimes rather different cruise tracks. The quantity of data generated by these two studies is too great to reproduce here. The McGill data is included in McGill University Marine Science Center Manuscript Reports summarized by Steven (1975), and the BIO data is available from the Marine Environmental Data Service (Ottawa). In order to illustrate the type of data available, the nitrate concentration is plotted against depth for data that is available from April and May for the region of the Gulf east of Gaspé for each year from 1970 to 1975 (Fig. 17). Some additional nutrient data for the estuary and/or the Gulf have been published by Sinclair et al. (1976); Therriault and Lacroix (1976); Sévigny et al. (1979); Greisman and Ingram (1977).

2.4 Biological Variables

2.4.1 Phytoplankton Biomass (Chlorophyll and Production)

It is difficult to look at the interannual differences in phytoplankton biomass and/or production in the Gulf of St. Lawrence system since a true time series data base does not exist

Figure 17 Concentrations of dissolved nitrate at various depths in the Gulf of St. Lawrence observed between 1970 and 1974. Data are summarized (left panel) from IBP data report series (Steven 1975) and unpublished data (right panel) from A. Coote, Chem. Oceanography, B.I.O., Dartmouth, N.S. A - minimum depth of the upper 1.5°C isotherm, B - minimum depth of temperature minimum, C - maximum depth of upper 1.5°C isotherm, D - maximum depth of temperature minimum. (From Appendix II.)


NITRATE (μg-at ℓ⁻¹)
0
5
10
15
20
25
DEPTH (m)
100
200
300
400
A
B
C
D
• IBP 1970
○ IBP 1971
• BIO 1972
○ BIO 1973
▲ BIO 1974
△ BIO 1975

for any location that could be compared to any other physical or biological (fisheries) time series. The only data that we have on the seasonal variations of phytoplankton biomass and/or production are the IBP studies of Steven (1975) who carried out seasonal observations between 1969 and 1971 at six stations located in different part of the Gulf system (Rimouski in the Estuary, Grande-Rivière in Chaleur Bay, Ellerslie in P.E.I., Cap Rouge in the Magdalen Islands, Bonne Bay in Newfoundland and Matamek near Seven Islands), the Georges Bay study in 1977 (Marine Ecology Laboratory 1980) and the two studies of Sinclair in 1974 (Sinclair 1978) and of Therriault and Levasseur in 1979 and 1980 (unpublished data) in the vicinity of Rimouski. The region facing Rimouski and Pointe-au-Père is that where there exists the most data for chlorophyll biomass estimates in the Gulf system. By combining all available data in this region, we can obtain six years of seasonal observations between 1969 and 1980. Figure 18 illustrates the kind of time series for chlorophyll a (integrated to about 50 m depth) we can observe in this region of the Estuary. This figure shows that large measurable interannual differences in chlorophyll concentrations occur that are difficult to explain with this very limited time series. Winter data are completely missing. Recently, high frequency temporal observations were carried out at Métis point (Therriault, unpublished data) for 120 days (Fig. 19) which indicate a very high day-to-day variance in the physical, chemical and biological data. From these data, we can conclude that if some temporal resolution is to be achieved, care should be taken to choose a high sampling frequency of at least 1 to 2 times per week.

2.4.2 Invertebrate Fisheries

Commercial exploitation of invertebrates in the Gulf of St. Lawrence has occurred at least since the visits of Basque, Portuguese, British and French ships to the area prior to 1600 (Johnston 1977). While harvesting of crustaceans (lobsters and crabs) and molluscs (soft and hardshell clams, oysters, scallops and squid) intensified during the 18th and 19th centuries, it was not until after Canadian Confederation that landed weights of specific fisheries in designated districts were recorded. These statistics compiled by the Department of Fisheries form a long term record from which historic changes in sizes of stocks of individual species may be inferred. However, effects of changes in fishing effort and techniques and the assumption that changes in the number or weight harvested actually reflect changes in total population abundance may hinder critical use of these records for this purpose.

Scientific description of invertebrate fauna in the Gulf of St. Lawrence was initiated by J. F. Whiteaves in 1870-71. He recorded marine invertebrate species occurrence throughout Canadian eastern coastal waters through expeditions sponsored by the Geological Survey of Canada. His observations (Whiteaves 1901) provided only qualitative measures of relative abundances of macrobenthic (individuals >5 mm) species but the catalogue continues to serve as a unique checklist for geographical distributions of marine invertebrates in this region.

Establishment of permanent research stations by the Biological Board of Canada in the early 1900's provided opportunities for fisheries investigations in eastern Canada at laboratories at Ellerslie (P.E.I.), Gaspé (Qué.) and St. John's (Nfld.). While some studies at these laboratories involved assessment of populations of various marine species, no long-term census of any commercial or non-commercial species was undertaken (Johnston 1977). Collections by Brunel (1970) of benthic invertebrates near Grande-Rivière , Qué. between 1951 and 1966 provide the only time series set of data from which changes in biomass over time might be evaluated.

In the absence of time series observations of actual abundance of invertebrate populations within the Gulf of St. Lawrence, statistical records of weight harvested by commercial fisheries serve as an historic record. Harvested weight clearly cannot always be assumed to be proportional to total population production. This is shown in the case of oyster production in P.E.I. and N.B. (Fig. 20). Medcof (1961) and Morse (1971) have documented changes in effort which have occurred in this fishery since the early 1900's. Oyster disease, probably introduced through imported stock, decimated oyster populations in western P.E.I. between 1916 and 1921, with a second outbreak following 1935. Disruptions associated with the effects of war and a third outbreak of the disease in the late 1950's in N.B. have caused large fluctuations in effort expended in this industry.These past biological and economic changes make it virtually impossible to draw conclusions concerning long-term trends in oyster abundance or production. Similar difficulties in interpretation exist for data from the scallop fishery in the Northumberland Strait (Jamieson, 1979).

Effects of changes in levels of effort expended in invertebrate fisheries within the Gulf of St. Lawrence are also probably reflected in variable annual landings of scallops and

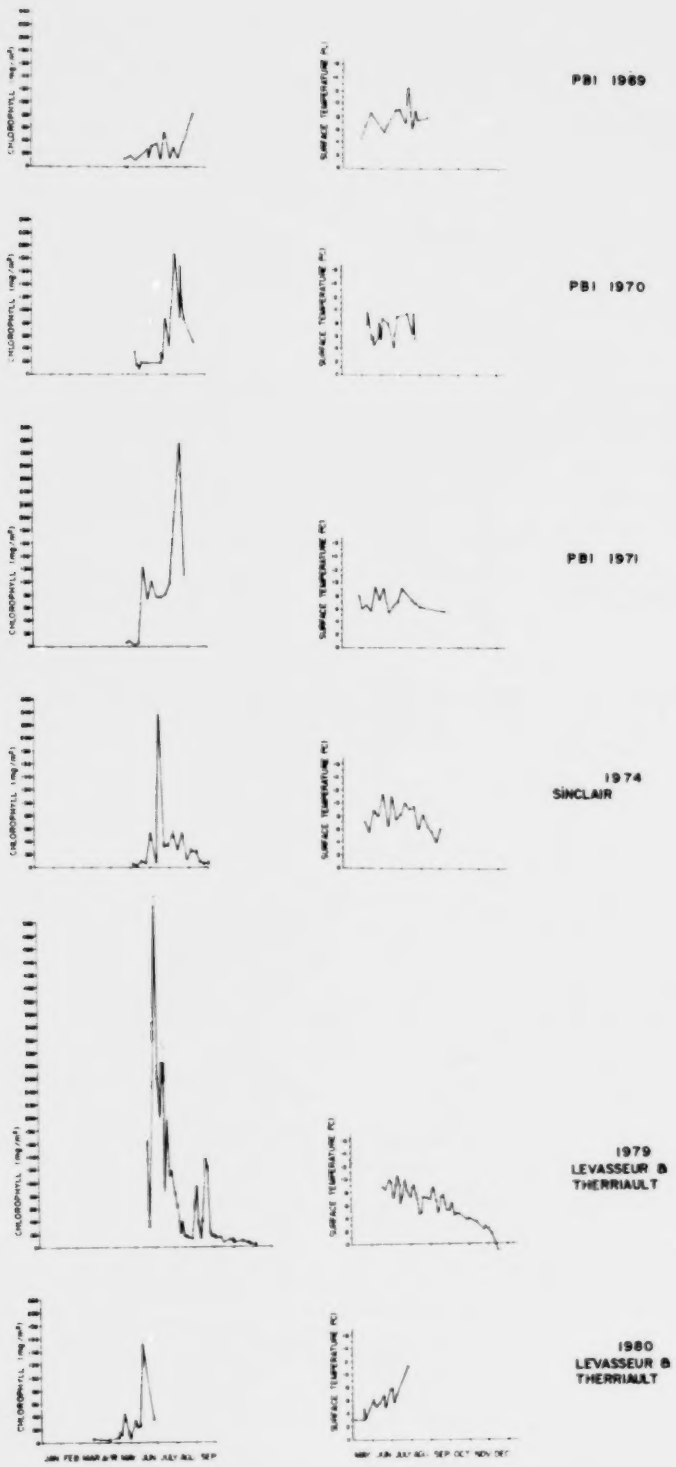


Figure 18 Summary of time series observations of surface temperature and chlorophyll a concentration to approximately 50 m depth in the St. Lawrence Estuary (several stations near Pointe-au-Père). (Unpublished data compiled by J.-C Therriault.)

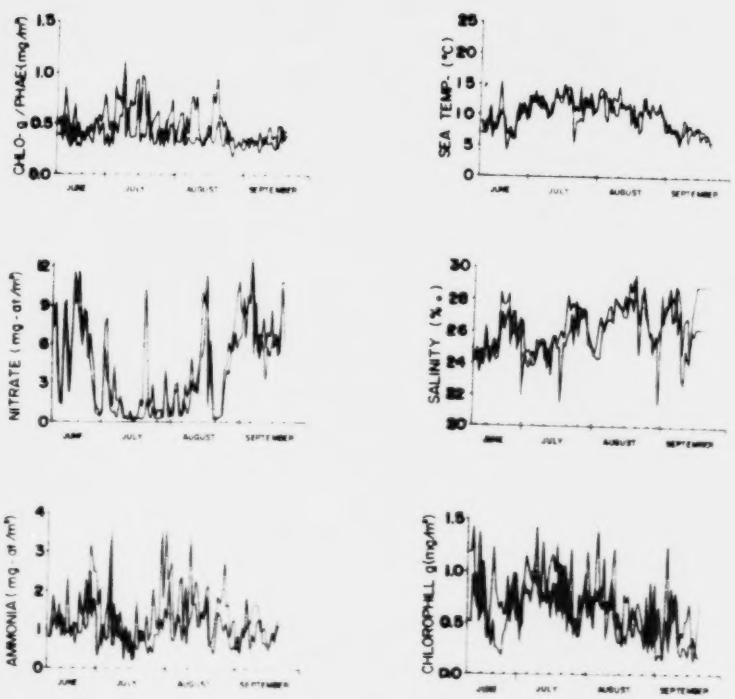


Figure 19 High frequency temporal observations (during daytime each day for 120 days) for physical and chemical variables and measures of phytoplankton pigment standing crop at 1 m depth nearshore during 1979 in the St. Lawrence Estuary at Métis point. Solid line - low tide, dotted line - high tide. (J.-C. Therriault, unpublished data.)

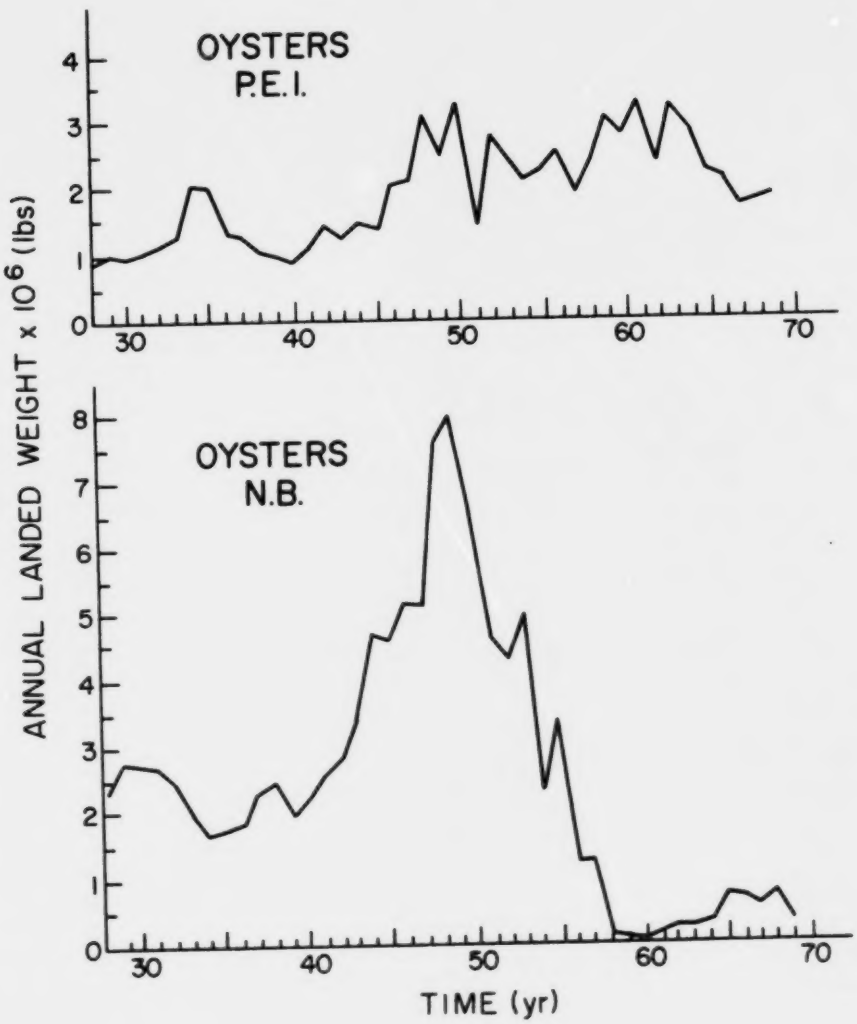


Figure 20 Landed weights of oysters (Crassostrea virginica) in Prince Edward Island and New Brunswick between 1928 and 1969 (from Morse 1971).

crabs in Québec (Table 3). Lobster (and perhaps soft-shell clam) fisheries yield however, may be interpreted differently. In both of these fisheries, effort has been sustained to remove a large proportion of the total number of individuals grown to sufficient size to be harvested in any year. Thus, even though several year classes may be represented in the catch, the annual harvest removes a large and probably rather constant proportion of the total number of individuals grown to sufficient size to be harvested in any one year. Shrimps are not listed, but this fishery is new.

Dow (1969) and Flowers and Saila (1972) considered relationships between water temperature and lobster yield in Maine and eastern Canada to conclude that positive correlations between landings and temperature were widespread. Winter temperatures six to eight years earlier provided the best estimator for predicting landings. Boudreault et al. (1977) carried out similar analyses by comparing lobster landings and yield/trap in the Magdalen Islands (Fig. 21). The general pattern of increases and decreases are similar by both measures and landings must reflect actual changes in abundance of lobsters of commercial size. Boudreault et al. (1977) used a linear regression of principal components to calculate that 84% of the variance in annual landings could be accounted for by surface water temperature during December and average winter temperatures 8.5 and 3.5 years earlier, respectively. Winter temperature was thought to influence larval survival probability and possibly growth to reproductive size within five years.

This analysis of the Magdalen lobster landings was predated by Sutcliffe's (1972) observations of positive correlations between discharge from the St. Lawrence River and annual lobster pack and soft shell clam catch of Québec (two year means). The most significant correlations were obtained with a lag equivalent to the approximate age at maturity or commercial size and it was concluded that runoff affected larval survival and growth in some positive way. In a subsequent study, the estimated abundance of lobster larvae (stage I) in Northumberland Strait (from Scarratt 1964) and June discharge of the Little South West Miramichi River in the same year were shown to be positively correlated (Sutcliffe 1973). The correlation decreased for larvae of increasing age and there was no significant correlation with St. Lawrence River discharge.Further analysis of the annual lobster landings from Québec (1930-1969) showed a significant correlation with April river flow 9 years earlier. Total lobster landings from Prince Edward Island were positively related to June runoff with an 8-year lag.

While correlations do not indicate a causality, Sutcliffe's observations imply that past changes in lobster landings in the Gulf are in some way related to changes in hydrographic features affected by or involving the discharge of freshwater. There should be coherence in changes in yield of the lobster fishery over time in different regions if the effects are widespread. Iles (1975) and Dadswell (1979) compared lobster landings in various statistical districts in Nova Scotia and concluded that changes in many areas over the past 30 to 40 years had occured synchronously. The patterns were thought to reflect the existance of recruitment cells where larvae are supplied from adjacent areas by advective flow. Effects of environmental changes or over fishing may occur in one area with resulting loss in recruitment transmitted 'downstream' over time.

Past changes in lobster landings in various parts of the Maritimes (by province, county and statistical district) have been summarized and discussed by DeWolfe (1974), Dadswell (1979), and Robinson (1979). Caddy and Chandler (1976) also reviewed some of the historical data for landings of various inshore species in the Maritimes from 1947-1973. Present statistical districts were established in 1947 and only data collected after this date can be analyzed by district. These data for lobster landings (summarized in Appendix II) were analyzed on a regional (rather than statistical district) basis to combine areas which might be considered to reflect different recruitment units (Dadswell 1979) (Fig. 22). Annual landings (without averaging) in 23 out of 55 comparisons were significantly correlated ($p < 0.05$, $n = 23$-40, $r^2 > 0.15$) (Tables 4 and 5). Areas within the Northumberland Strait demonstrated the greatest coherence for year to year changes in yield, however, significant similarities also existed between landings in these areas and those along the Atlantic coast of Newfoundland (Table 5).

The coincidence in trends of lobster landings between some areas within and outside of the Gulf supports the view that factors affecting annual landings (or population size) act in a widescale manner. It is not necessary that effects of temperature or runoff discussed by Sutcliffe (1973) influence lobster populations equally in all regions. The widespread impact could be modified by local conditions. Freshwater discharge in Northumberland Strait could have a localized effect which need not be correlated with events over larger areas (Sutcliffe 1973).

TABLE 3. Total Québec invertebrate fisheries landings (lbs x 10^3 y^{-1}) (Provincial Statistics).

Year	Soft-shell clams	Scallops	Lobsters	Crabs
1948	400	-	2394	-
49	732	-	2073	-
50	632	16	2278	-
51	448	3	2388	-
52	639	4	2314	-
53	609	1	2646	-
54	412	3	2804	-
55	1075	-	2747	-
56	1329	21	3653	-
57	1139	-	3088	-
58	1249	-	2698	-
59	1248	-	3178	-
60	946	2	3552	-
61	1519	3	3414	-
62	1614	3	4228	-
63	971	8	3829	-
64	1093	3	3170	-
65	372	409	1890	-
66	454	101	2028	-
67	82	133	1761	-
68	191	411	1743	-
69	552	979	2387	4167
70	380	1098	2635	3810
71	382	438	2443	1819
72	1435	283	2225	1780
73	728	181	2162	2611
74	920	134	3216	2462
75	1013	1363	2654	1324
76	804	2692	2873	3296

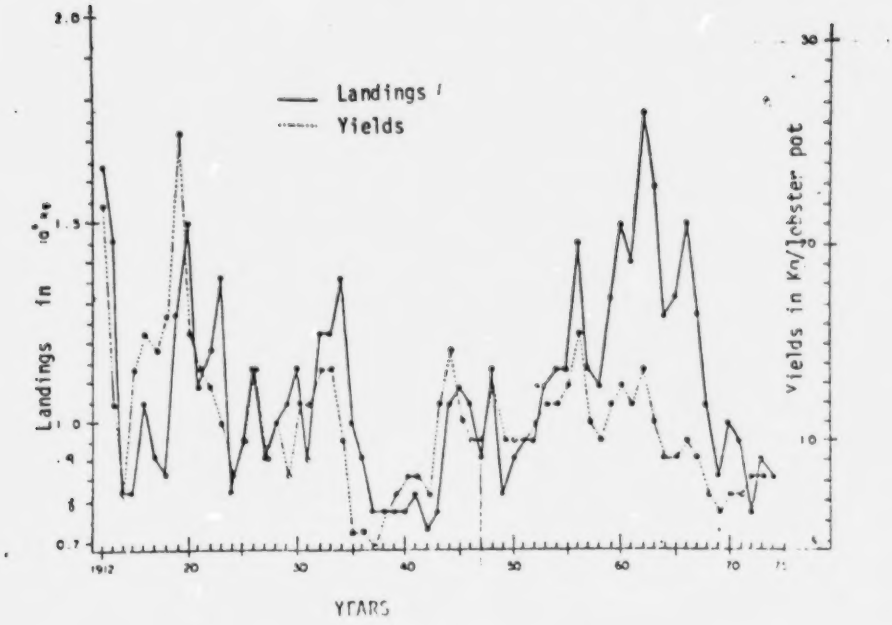


Figure 21 Time series of annual lobster landings and yields in the Magdalen Islands (1912-1974). (Boudreault et al. 1977).

Figure 22 Regional areas defined for comparison of annual landings of lobsters. Numbers refer to fisheries statistical districts combined to calculate total landings (Appendix II).

1. Qué. 8,9,10,11,12,13,14,15; N.B. 63,64,65,66,67,68 (Chaleur Bay)
2. N.B. 70,71,73,75,76,77 (Northumberland-Kent)
3. N.B. 78,80,45,46; N.S. 10,11 (Central Strait)
4. N.S. 12,13,3 (South Strait)
5. N.S. 2 (North Inverness)
6. Qué. 26,27,28 (Magdalen Islands)
7. P.E.I. 82,83,85,86,87 (P.E.I. Strait)
8. P.E.I. 88,96,95,93,92 (P.E.I. Gulf)
9. Nfld. K,L,M,N (Nfld. North Gulf)
10. Nfld. G,H,I,J (Nfld. South Gulf)
11. Nfld. A,B,C,D,E,F (Nfld. Atlantic Coast)

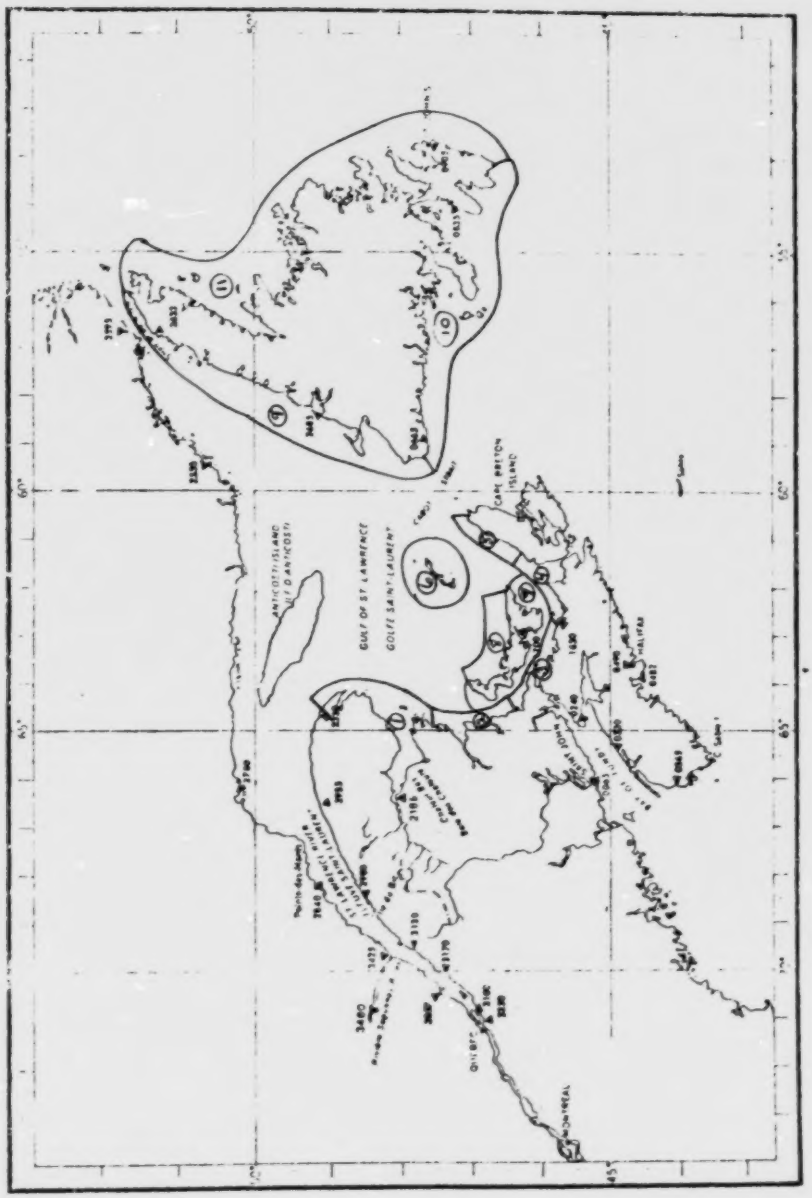

GULF OF ST LAWRENCE
GOLFE SAINT-LAURENT
ANTICOSTI ISLAND
ILE D'ANTICOSTI
CAPE BRETON ISLAND
MONTREAL

TABLE 4. Linear correlation coefficients (r^2) of comparison of annual lobster landings for different regions in the Gulf of St. Lawrence and Newfoundland. Data presented in Appendix I and regions identified in Fig. 22.

		2	3	4	5	6	7	8	9	10	11
Chaleur Bay	1	0.41	0.38	0.12	0	0.32	0.45	0.21	0.04	0.35	0
Northumberland -Kent	2		0.29	0.56	0	0.04	0.70	0.04	0.08	0.26	0.05
Central Strait	3			0.54	0.57	0.12	0.39	0.12	0.04	0	0.45
South Strait	4				0.01	0.05	0.59	0.02	0.04	0.02	0.50
North Inverness	5					0.07	0.10	0.26	0.20	0	0.01
Magdalen Is.	6						0.29	0.12	0	0.15	0.32
P.E.I. Strait	7							0.06	0.04	0.12	0.43
P.E.I. Gulf	8								0.02	0.22	0
Nfld. NorthCoast			9								0.01 0.06
Nfld. SouthCoast			10								0.14
Nfld. AtlanticCoast			11								1

Values underlined indicate significant correlation coefficients ($P<0.05$).

TABLE 5. r^2 values from Table 4 >0.15 tabulated in decreasing value. n = number of years compared in deriving correlation coefficients.

Areas	Regions Compared	n	r^2
2/7	Northumberland-Kent/PEI Strait	23	0.70
4/7	South Strait/PEI Strait	23	0.59
3/5	Central Strait/North Inverness	33	0.57
2/4	Northumberland-Kent/South Strait	33	0.56
3/4	South Strait/Central Strait	33	0.54
4/11	South Strait/Newfoundland-Atlantic Coast	27	0.50
3/11	Central Strait/Newfoundland-Atlantic Coast	27	0.45
1/7	Chaleur Bay/PEI Strait	23	0.45
7/11	PEI Strait/Newfoundland-Atlantic Coast	27	0.43
1/2	Chaleur Bay/Northumberland-Kent	40	0.41
3/7	Central Strait/PEI Strait	23	0.39
1/3	Chaleur Bay/Central Strait	40	0.38
1/10	Chaleur Bay/Newfoundland-South Coast	27	0.35
1/6	Chaleur Bay/Magdalen Islands	40	0.32
6/11	Magdalen Islands/Newfoundland-Atlantic	27	0.32
6/7	Magdalen Islands/PEI Strait	23	0.29
2/3	Northumberland-Kent/Central Strait	40	0.29
2/10	Northumberland-Kent/Newfoundland South Coast	27	0.26
5/8	North Inverness/PEI Gulf Coast	23	0.26
8/10	PEI Gulf Coast/Newfoundland South Coast	23	0.22
1/8	Chaleur Bay/PEI Gulf Coast	23	0.21
5/9	North Inverness/Newfoundland North Coast	27	0.20
6/10	Magdalen Islands/Newfoundland South Coast	27	0.15

Also discharge of the St. Lawrence River reflects flow from the Great Lakes and this flow may not be correlated with specific climatic events in a localized area within or outside of the Gulf. Relationships between runoff, some physical factors which might affect lobster larval survival and the effect of runoff regulation will be considered below.

2.4.3 Vertebrate Fisheries

Although there has been a commercial fishery (predominantly for for cod) in the Gulf of St. Lawrence for hundreds of years, information from the Gulf fisheries on stock biomass or year-class strength variability is only available for the last twenty years at most. The major commercial finfish species in the Gulf of St. Lawrence are cod (two stocks - 4T-Vn, 4RS-3Pn) redfish (one stock - 4RST), American plaice (one stock - 4T) and herring (2 stocks - "Southern Gulf" and "West Newfoundland"). In addition a large portion of the western Atlantic mackerel stock (NAFO 3 - 6) spends the summer in the Gulf of St. Lawrence, even though there is a very small Canadian fishery. In recent years the Greenland halibut fishery has become important.

There are four sorts of data available - landings, catch per unit of effort (CPUE), research vessel surveys and cohort analyses. The latter provides estimates of both stock biomass and year-class strength variability. The time series on landings are of course the longest. However there are serious constraints on the use of these data as an indication of stock size changes. For example, the catches of both cod and herring prior to the 60's are thought to reflect changes in market demand rather than population fluctuations. Secondly, major gear changes have occurred in recent decades when the markets have become more elastic (e.g. mesh size changes for cod fishery in the late 1950's, introduction of the purse seine fishery for herring in the 1960's). A further complication is that landings in earlier time periods are not reported in appropriate geographic detail to conform to the presently accepted management or stock units (e.g. cod landings in 4V are not separated into 4Vn and 4Vs subareas prior to the 1960's). Because of these constraints the finfish landings are not considered useful as indicators of stock size fluctuations.

The relative importance of groundfish stocks in the Gulf of St. Lawrence is shown in the recent landings of different species (Fig. 23). Examples of stock size fluctuations and year-class strength variability are presented in Figs. 24 and 25. There appears to be some degree of parallelism in year-class strength. The two stocks of both cod and herring, over the short time period for which there are common estimates, show similar overall trends (Fig. 24). There is also the suggestion that in recent years several of the stocks are responding similarly although not completely in phase - mackerel peaks in 1967 and 1974, herring in 1968 and 1974, and cod in 1968 and 1975, for example. For all of the above there were weak year-classes in the intervening years. Redfish, even though the time series is very short, appears to be out of phase.

Examples of the stock size fluctuations are indicated in figure 25. There is good evidence that stock sizes for several species were depressed in the mid 70's. However, a large part of the recent variability must be a function of the fishery and the associated management regime. The cod time series however does suggest cycles of approximately 8 years in duration. Research vessel survey data, although of high quality, is too short to be used for comparison with this data. It does however confirm the recent increase in 4T cod biomass indicated from fishery-dependent data sources.

2.5 Adequacy of Data Sets for Evaluating Runoff Effects

There are a limited number of oceanographic and fisheries time series data that are useful for the purposes of evaluating the importance of freshwater runoff (and its regulation) on the marine environment. The effect of regulation on the seasonal runoff itself is well documented. There is also a relatively complete spring to autumn description of salinity and temperature in the Gulf of St. Lawrence from the late 50's to the present. The surface temperature observations at two shore stations complement the hydrographic data base. Without further analysis, the sea level data, do not appear to be useful for the purposes of this report. There are essentially no time series data of an appropriate length for nutrients and plankton variables. Lobster landings statistics are potentially useful if the assumption of constant effort is appropriate. There are some relatively long (15 to 20 years) time series for fish populations. These data sets have the advantage (in contrast to the lobster landings) of including estimates of yearclass strength and annual population abundance. The longest time series are

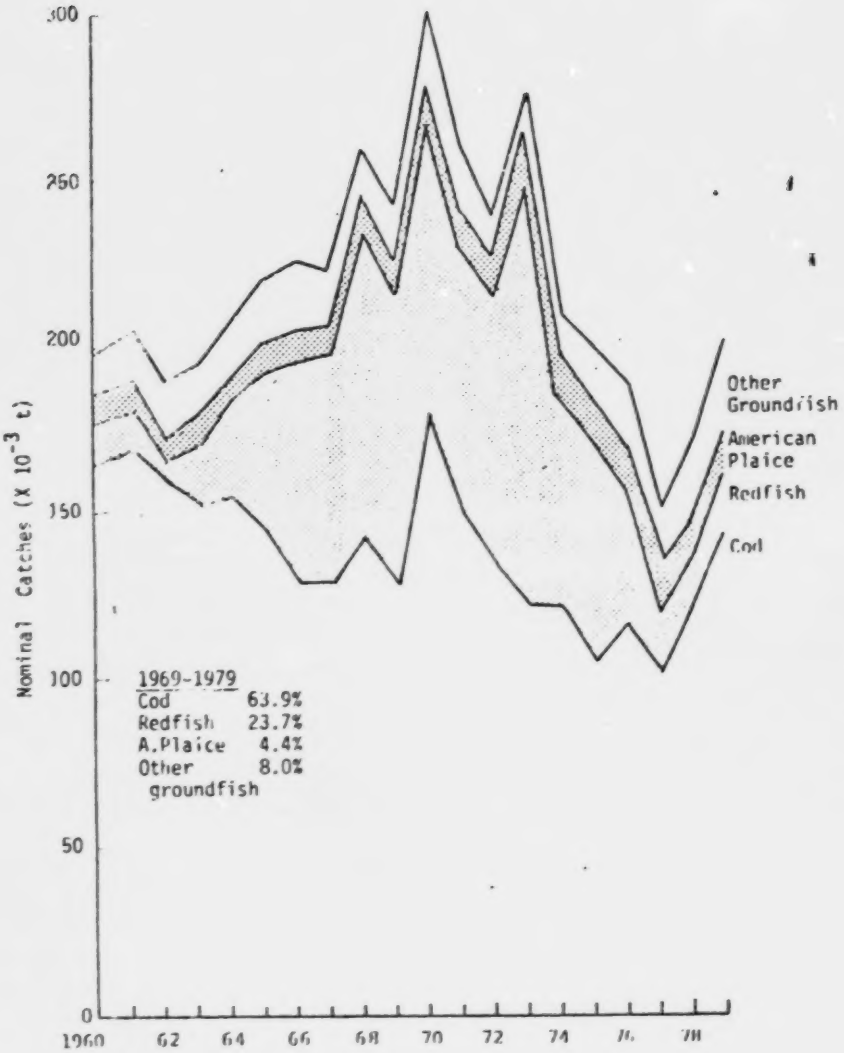


Figure 23 Nominal catches of major groundfish species in Gulf of St. Lawrence 1960-79. NAFO Divisions included: Cod-Subdivision 3Pn, Division 4RST, Subdivision 4Vn. All other species-Division 4RST only. (Halliday and Pinhorn 1980).

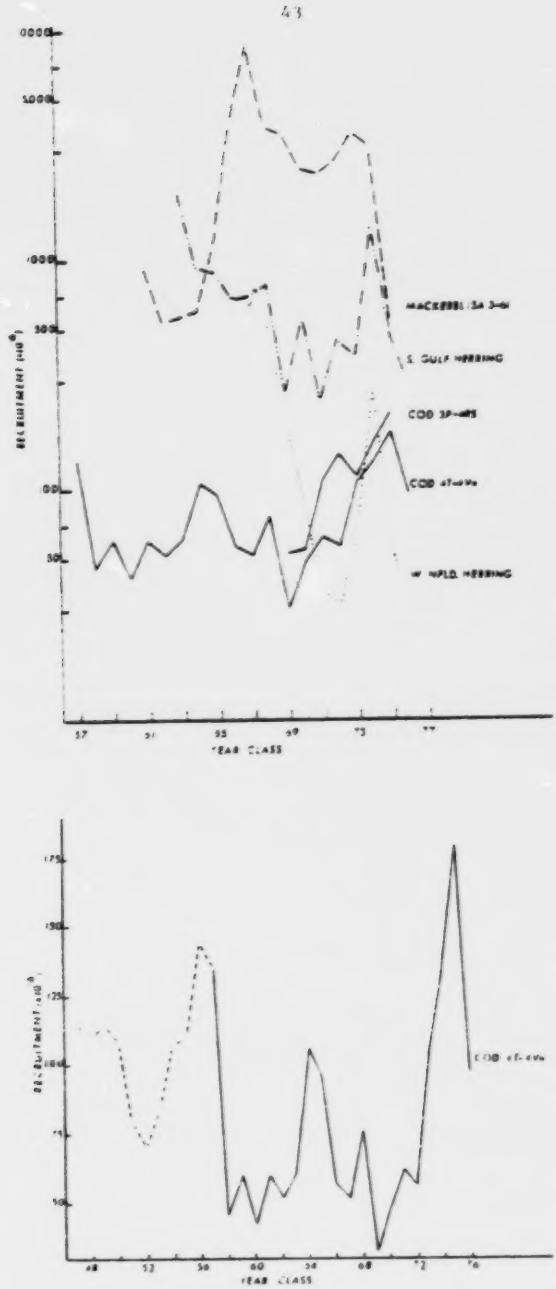


Figure 24 Estimates of year-class strength variability (by number) for some Gulf of St. Lawrence stocks. Recruitment estimates prior to 1956 are less reliable than in later years because the catch matrix for cohort analysis is difficult to construct. (Data taken from recent CAFSAC research documents.)

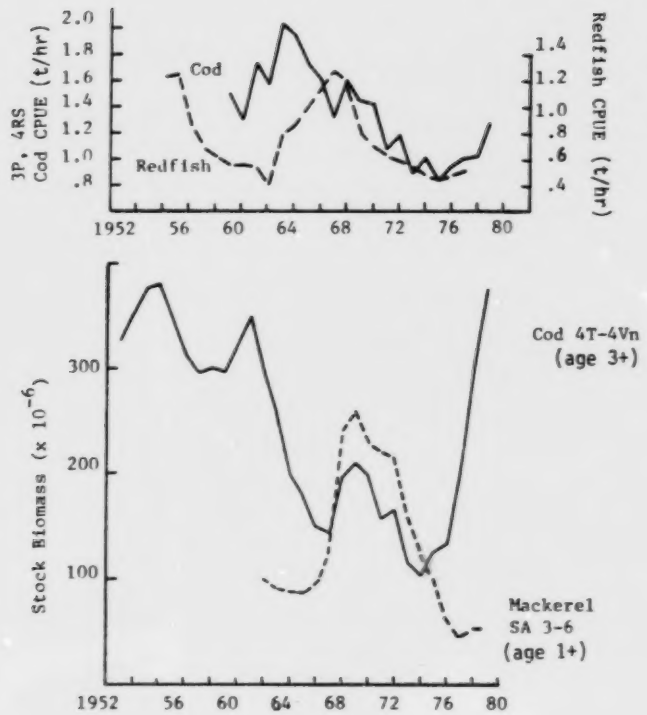


Figure 25 Fish stock biomass trends for various species in different areas of the Gulf of St. Lawrence (Data taken from recent CAFSAC research documents).

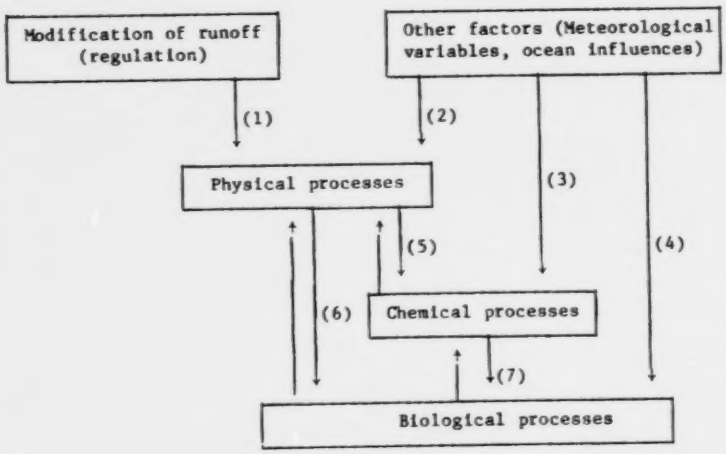
those for Southern Gulf cod (including yearclass strengths from 1947 to the present).

In summary there is some time-series information on physical characteristics of the Gulf and on commercially fished populations, but essentially nothing in between. The limitations imposed by the available data dictate the sorts of analyses that can be attempted at present.

3. MECHANISMS OF POSSIBLE FRESHWATER EFFECTS IN THE GULF OF ST. LAWRENCE

3.1 General Pattern of Inter-relationships in the Marine Environment

The following block diagram illustrates interrelationships between the various physical, chemical and biological processes we can observe in a typical marine environment.



As we can see, freshwater discharge into the marine system can affect a variety of physical processes (arrow 1 in the diagram) which, in turn, can have a profound influence on the chemical (arrow 5) and biological (arrow 6) processes. But other factors may also have an important effect on the chemical (arrow 3) and biological (arrow 4) process in this system. For example, solar radiation can influence productivity through changes in surface mixed layer depth, but it also directly controls the rate of phytoplankton photosynthesis. On the other hand, regulation of riverflow is only one of the many factors (arrow 2) which could affect the circulation and distribution of properties in the system. The block diagram also shows that chemical and biological processes are closely interrelated (arrow 7) and that they can also influence the physical processes (arrows 5 and 6), for example, by modifying the turbidity of the waters.

Thus after examination of the block diagram, it becomes clear that the way regulation can affect biological cycles is both indirect and non-unique, and that if the effects of regulation on the marine environment are to be fully understood, we must have sufficient knowledge of appropriate relationships (arrows) in this complex system. We might be able to gain some insight of the mechanisms of possible freshwater effects in action in the marine environment by looking, through this diagram, at the information that has been accumulated by various investigators in the Gulf of St. Lawrence system over the past twenty years or so.

3.2 Interactions between Runoff and Physical Processes

The main physical processes that are directly affected by runoff regulation in the Gulf of St. Lawrence are the circulation and the mixing patterns, and the ice formation and distribution processes. As the freshwater from the St. Lawrence River enters the estuary, it drives an estuarine circulation with an outflow of freshwater in the surface layer and an inflow of salt

water in the lower layer. At the fresh-salt water interface, complicated entrainment and mixing processes take place. The parameters which control the rate of entrainment and mixing appear to be the amount of freshwater inflow, the strength of the tidal current, and the width and depth of the estuary (Bowden 1967, Pritchard 1967). In a highly stratified estuary with weak tidal action, entrainment can occur by the upward movement of salt water across the interface. In a moderately stratified estuary, the dominant mixing agent is turbulence caused by tidal action. This is the classification that the St. Lawrence Estuary falls into (Forrester 1967). Turbulent eddies transport freshwater downward and carry salt water upward, in contrast to the dominantely upward advection of salt water in a strongly stratified estuary. This type of two-way mixing contributes a great volume of salt water to the upper seaward flowing layer. The horizontal volume transport in both the upper and the lower layers is much greater than in a highly stratified estuary. The physical mechanism which generates the estuarine circulation pattern, outflow in the upper layer and inflow in the lower layer, is that the increased potential energy resulting from mixing produces a high horizontal pressure gradient which drives the circulation. The horizontal transport and mixing depend on the river inflow, the tidal velocity, diffusion, gravitational convection and the wind stress in an interrelated way. Analytical solutions of the circulation problem taking into account all of these factors have been given by Hansen (1967) and Rattray and Hansen (1962). In general, if all other factors are held constant, an increase in the river inflow will increase the horizontal mass and salt transports. However, a major problem in studying the effect of runoff on estuarine circulation is to determine the sensitivity of mixing and circulation to each factor affecting the dynamics.

Another important physical process in the St. Lawrence estuary is upwelling in the region of the head of the Laurentian Trough. An intense mixing process linked with the generation of large amplitude internal tides is responsible for the upwelling of subsurface waters in this region of the Estuary (Forrester 1974, Ingram 1975, Therriault and Lacroix 1976). It is not clear at present how this upwelling process can be related to freshwater runoff but the most probable influence of runoff is by affecting the intensity of the mixing process.

Around Pointe-des-Monts, the classical picture of estuarine circulation does not hold. As the low-salinity water flows past Pointe-des-Monts, it experiences a sudden increase in the width of the channel. As a result of change in the cross-channel length scale, the dynamics for the circulation and mixing also change. Tidal action plays a less important role in mixing than in the estuary. The Coriolis effect becomes a major factor in determining the magnitude and direction of the surface current. Recent observations by Tang (1980) show that the low-salinity water separates from the north shore near Pointe-des-Monts and forms a sharp salinity front across the mouth of the estuary. Associated with the front is an along-front surface current towards the south shore. Both the frontal structure and the along-front current continue to the Gaspé coast to be known as the Gaspé Current. This frontal system appears to be highly seasonal, being strongest in the summer, weaker in the late fall and disappearing in the late winter. Upwelling of subsurface waters is associated with the frontal system. This is evident from both hydrographic data and satellite images in which a band of cold water can often be seen along the front. From a model study, the rate of frontal upwelling increases with the along-front horizontal volume transport (Tang 1980). Thus, frontal activity should be directly related to freshwater runoff.

Outside the frontal zone of the northwestern Gulf and further downstream in the Magdalen Shallows the oceanographic conditions undergo further changes and the system behaves more like a shallow marginal sea. The influence of the estuary on the circulation and mixing becomes minimal. The water column is characterized by a well-mixed upper layer of a thickness of about 20 m and a temperature minimum at about 60 m in the summer, and a homogeneous layer down to about 90 m in the winter. Below 90 m differences in temperature and salinity between the seasons are very small. The mechanism of mixing here is quite different from that in either the estuary or in the frontal zone of the northwestern Gulf. Here both tidal mixing and upwelling are weak. The primary cause of mixing is the shear instability of the flow.

Shear instability is controlled by the Richardson number:

$$R_i = \frac{g}{\rho} \frac{d\rho/dz}{(du/dz)^2},$$

where g, ρ, u and z are the gravity, density, horizontal velocity and vertical coordinates

respectively. The shear instability increases with decreasing R_i. Thus a strong velocity shear or a weak stratification tends to enhance mixing. A change in the freshwater runoff is not likely to affect the shear because the currents are largely wind driven. The effect of runoff can only be felt through change in stratification. Consequently, an increase in runoff is expected to suppress mixing and vice versa.

The overall effect of the regulation of river discharge for the purpose of hydroelectric power production in areas such as the Gulf of St. Lawrence is to decrease the river discharge in the spring and to increase the winter discharge (Jordan 1973). This decrease in the spring discharge cuts down on the buoyancy flux to the surface layers of the ocean during the time when the surface mixed layer is being set up, and thus may have a profound effect on the characteristics of this layer.

Figure 26 indicates the surface salinity of the Gulf waters from all available bottle data from MEDS. The years from 1900 to the present were divided on the basis of fresh water discharge from Lake Ontario. The standard deviation of the series of annual average discharges was calculated and those years which had an average discharge which was more than one half a standard deviation higher than the overall series mean were termed "high" discharge years. And those years which had an average discharge more than one half a standard deviation lower were termed "low" discharge years. The figure shows three month average surface salinities from the high years and low years. As shown in the figure, the surface salinities over the southern Magdalen Shallows are 1°/$_{oo}$ less during the high discharge years, a factor which must have a large effect on vertical processes.

The reduction in surface layer salinity over the Magdalen Shallows during high runoff years supports the conclusion that the entrainment ratio[1] within the Gulf is not constant. It should be noted, however, that increased runoff, even though it may suppress mixing, may still result in a greater absolute vertical entrainment of salt (and nutrients). It is inferred that the relationship between entrainment and runoff is non-linear, but the nature of the non-linearity is not known. The following figure graphically represents two possibilities:

freshwater runoff into the Gulf

The relationship on the left implies that vertical transport of salt and nutrients continuously increases, albeit at a decreasing rate, with runoff increases. In contrast, on the right, entrainment decreases at high runoff levels.

The implications on such things as plankton production processes and on volume transport out of the Gulf are critical to the following discussion. Some inferences on the form of the relationship may be forthcoming from a study of surface transport through Cabot Strait in relation to runoff.

On the upper layers of the ocean, the main turbulent energy balance is between the production of turbulence through the Reynolds stress and the suppression or enhancement through the surface buoyancy flux (Phillips 1966). In the Gulf of St. Lawrence, once away from areas where other mechanisms are more important, this turbulent energy balance will govern the surface layer dynamics. The ratio between the buoyancy supplied by the surface heat flux and that supplied by freshwater discharge may be written

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[1] The ratio of the sum of the fresh water discharge and the entrained volume to the fresh water discharge.

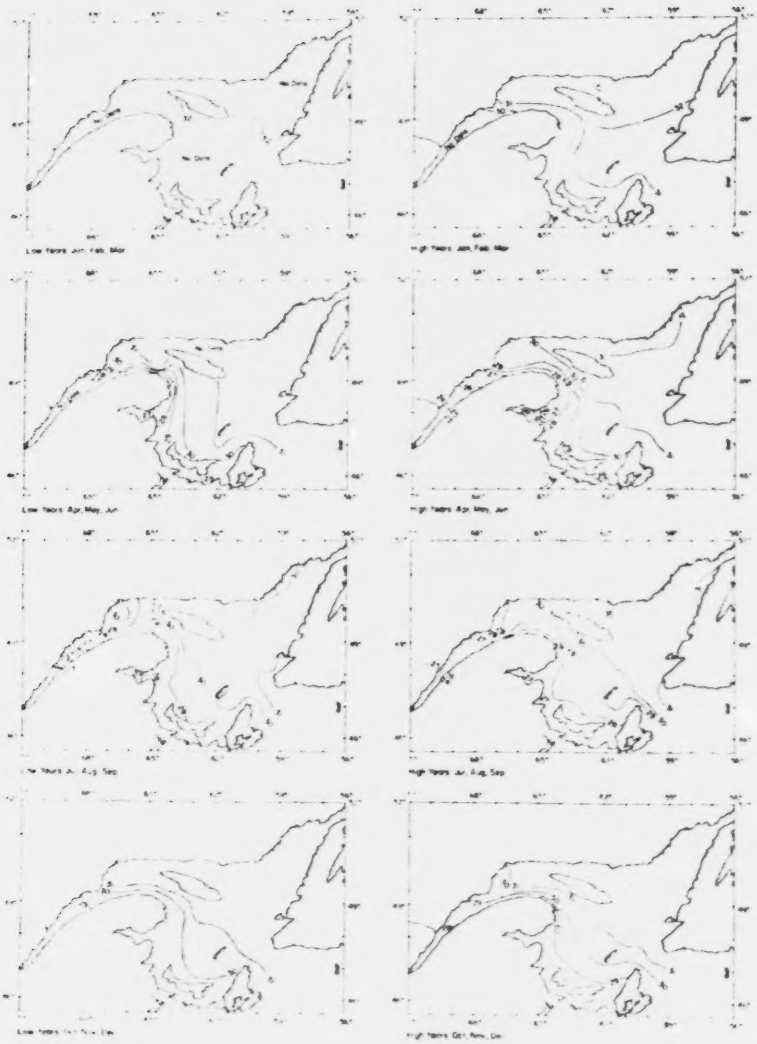

Figure 26 Surface salinity in the Gulf of St. Lawrence for years of high and low river discharge. The standard deviation of annual average discharges from 1900 to the present (Appendix II) was calculated. Years of high and low discharge were considered to be those when annual average discharge varied from the long-term mean by more than one half a standard deviation.

$$\frac{Q_H \alpha A}{\rho_w C_p Q_F S} \qquad (1)$$

where Q_H is the surface heat flux, α the coefficient of thermal expansion, A the surface area of the region under consideration, ρ_w the water density, Cp the specific heat, Q_F of the freshwater discharge and S a typical surface salinity. This calculation assumes that buoyancy is added to a particular region of the Gulf by two sources - as fresh water input added instantaneously to the surface over in this area (taken as fresh water discharge during April and half of May) and as heat added as surface heating over the same region and same interval. No consideration is given to horizontal gradients or advective transport. The region is, in essence, considered as a closed box. Using values typical for the month of April in the Gulf of St. Lawrence and a surface area appropriate for the Estuary, Gaspé Current and Magdalen Shallows (the area where most of the freshwater from the St. Lawrence system is confined) the ratio becomes 0.9. Thus we see that both freshwater discharge and surface heat flux are equally important so far as the surface buoyancy flux in April is concerned.

A length scale called the Monin-Obukhov length may be calculated from the ratio of the turbulent energy input at the surface to the buoyancy flux (Phillips 1966). This length scale may be interpreted physically as the depth at which the energy input and buoyancy flux terms become comparable in the turbulent energy flux equation. If the main energy input is from the surface wind stress, as over the Magdalen Shallows in the Gulf of St. Lawrence (Blackford 1978), this length scale should be related to the surface mixed layer depth. Under these conditions, the Monin-Obukhov length may be written

$$L_b = \frac{\left(\frac{\rho_a}{\rho_w} C_d\right)^{3/2} V_{10}^3}{\frac{Kg}{\rho_w}\left\{\frac{Q_H \alpha}{C_p} + \frac{\rho_w Q_F S}{A}\right\}} \qquad (2)$$

where ρ_a is the air density, C_d the air-water drag coefficient, V_{10} the wind speed at 10 metres, g the acceleration due to gravity and K the von Karman constant.

A given surface heat flux mixed over a depth D will result in a rate of temperature change over this depth of

$$\Delta T = \frac{Q_H}{\rho_w C_p D} \qquad (3)$$

Values for this projected temperature rise over the months of April and May using heat flux and wind speed values for the years 1960 to 1970 taken from weather stations surrounding the area of interest are given in Table 6. Freshwater discharge values are taken from (Jordan 1973) and the depth in equation 3 is taken to be the calculated Monin-Obukhov length.

A linear regression between the surface temperature at Grande -Rivière in May and the sum of the April and one half the May projected temperature rise is shown in Fig. 27a. The correlation between the two series is 0.73. A linear regression between the same temperature series and the same weighted average of the heat flux alone is shown in Fig. 27b. The correlation here is only 0.46. Thus 32% more of the variance is explained by a consideration of the factors determining the depth over which the surface heat flux will be mixed.

TABLE 6. Calculated vertical length scales and projected temperature rise over this depth in the Gulf of St. Lawrence. The second column for each entry shows the values calculated for estimated unregulated freshwater discharges. See text for explanation of last column.

	April L_b (m)		April $Q_H/\rho_w C_p L_b$ °C/month		May L_b (m)		May $Q_H/\rho_w C_p L_b$ °C/month		May To °C		
	Actual	Unreg.	Actual	Unreg.	Actual	Unreg.	Actual	Unreg.	Obs.	Cal.	Unreg.Cal.
1960	29		3.0		28		4.8		4.6	4.7	
1961	33		2.2		25		5.0		3.8	4.2	
1962	32		2.6		24		4.5		3.9	4.3	
1963	54		1.1		25		5.6		3.9	3.5	
1964	29	26	3.1	3.4	26	22	4.4	5.2	4.3	4.6	5.2
1965	36	34	2.7	2.8	25	19	4.7	6.2	3.6	4.4	5.2
1966	32	32	2.5	2.5	26	24	4.6	5.0	3.2	4.2	4.4
1967	42	40	1.3	1.4	33	28	2.9	3.4	2.9	2.5	2.8
1968	35	31	2.5	2.8	19	17	6.8	7.6	6.5	5.1	5.7
1969	36	37	1.2	1.2	22	20	5.1	5.6	3.7	3.4	3.6
1970	28	29	2.6	2.6	21	18	5.5	6.5	5.3	4.7	5.2

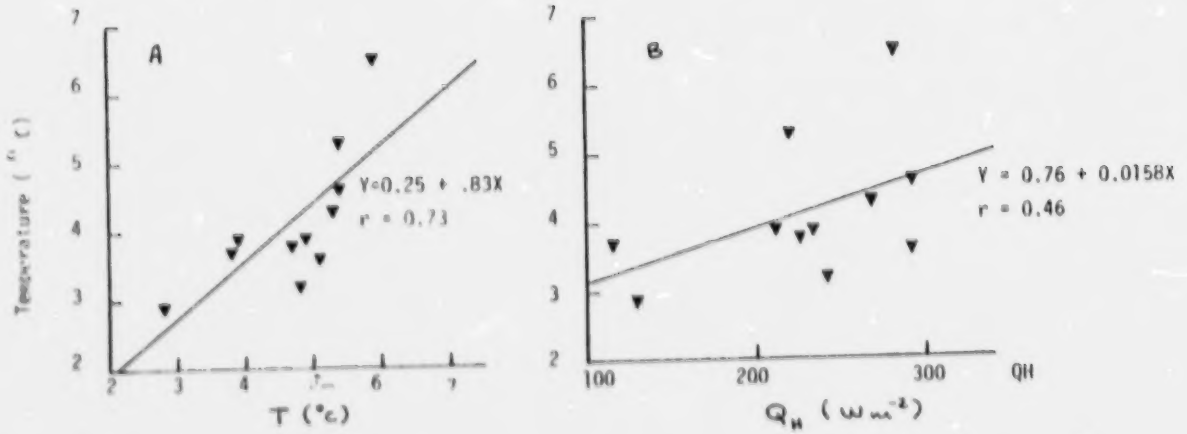

Figure 27. Calculated temperature rise over April and May (from equation 3) compared with observed

A temperature at Grande-Rivière during May.

B Surface heat flux (Q_H) compared with actual temperature at Grande-Rivière during May.

The linear regression shown in Figure 27a enables us to estimate the effect of the regulation of river discharge on the surface temperature of the southern Gulf waters. Jordan (1973) has estimated what the discharge would have been if regulation had not occurred by looking at the changes in stored volume over the years 1964 to 1970. By recalculation of the projected monthly temperature rises using these estimated natural discharges and inserting these figures in the linear regression equation shown on Fig. 27a we calculate the temperature of the surface waters without regulation. These values are shown in Table 6. Although the projected changes from regulation are barely significant in terms of the error of the least squares fit, the indication is that regulation could have caused changes in temperature of the upper layer on the order of 0.5° C. This may be biologically significant in terms of egg and larval development time (Palmer and Coull 1980) and further examination is certainly warrented.

As we have already demonstrate , the surface buoyancy fluxes from freshwater discharge and surface heat flux are of comparable magnitudes in the spring when the surface mixed layer is being set up. To a certain extent the same considerations apply during the fall when surface cooling is taking place. The intermediate cold layer is almost entirely formed by surface cooling during the winter in the Gulf of St. Lawrence (Banks 1966). This water appears to form the bulk of the water upwelled later in the year and any factor which is likely to affect its characteristics bears further examination. The increased freshwater discharge in the winter brought about by regulation may inhibit or prevent the convection brought about by surface cooling through an increased positive buoyancy flux. This also has implications as far as ice formation is concerned. The effect upon ice formation will not result from a decreased freezing point through a decreased salinity as this effect can be shown to be very minimal for the salinity changes expected. It will result from changes in the extent of vertical mixing through increased stratification. An indication that at least natural variations in fall and winter river discharge have had an effect on the depth of vertical mixing is provided by a correlation of -0.73 between the depth of the lower 1.5°C isotherm, (considered by Banks 1966 to be the lower bound of the intermediate water), and the winter freshwater discharge. This would appear to be significant, but further examination is needed.

In summary, some evidence does exist that regulation has had an effect upon the physical characteristics of the Gulf of St. Lawrence which may be biologically significant. Data exist with which a further examination could be undertaken. It can also be concluded that different dynamics operate in different regions of the Gulf of St. Lawrence system. It is therefore expected that the chemical and biological cycles will respond differently to freshwater runoff modifications, depending on the region of the Gulf system considered. This is consistent with the biological production results of Steven (1975) who divided the Gulf system into three separate regions based on important differences in the mechanisms of nutrient supply.

3.3 Interactions between Runoff and Chemical Variables

The most important mechanisms of nutrient enrichment of an estuary are the river flow into the estuary, which carries pollutants and plant nutrients leached from the soil, and entrainment and mixing at the freshwater-salt water interface, which transport the nutrient rich salt water to the surface (Ketchum 1967). In the St. Lawrence estuary (the region between Ilesaux-Coudre and Pointe-des-Monts) the relative contribution of the two sources has been estimated by Greisman and Ingram (1977). They found that river-derived nutrients were responsible for roughly only one-fifth of the nutrients introduced into the euphotic zone in the maritime estuary. In other words, entrainment and mixing at the interface and upwelling processes due to internal tides (Ingram 1975, Therriault and Lacroix 1976) are much more efficient mechanisms for supplying nutrients for biological production in the surface waters of the St. Lawrence estuary than is introduced by river flow.

The levels of nutrients in the intermediate and deep waters of the Gulf of St. Lawrence are three to four times the levels at similar depths in the northwest Atlantic outside the Gulf of St. Lawrence. There is also a definite trend of increasing nutrient levels in the Laurentian Trough from Cabot Strait to the head of the trough.

The gradients in nutrient concentration and the generally elevated levels within the Gulf are maintained by the biological cycling of nutrients. Settling of biological detritus from surface waters introduces nutrients to the deep water where they are regenerated and transported further into the Gulf by the residual movement of deep water towards the head of the Laurentian Trough. Upwelling, entrainment or other modes of vertical mixing will return the nutrients to the surface water where they again become involved in biological cycling. The net

result is an outward (toward Cabot Strait and the North Atlantic) movement of nutrients in the surface layer with biological utilization and subsequent particulate matter settling, followed by regeneration and inward transport of the nutrients in the deeper layer resulting in higher nutrient concentrations within the Gulf.

Nutrient supply to the surface layer can be considered to consist of two distinct phases. First, the nutrient input to the surface layers in winter by both freshwater input and vertical mixing, entrainment or upwelling provides a supply of nutrients in surface waters for spring production. Secondly mixing throughout the spring and summer will contribute to the nutrient supply necessary for the maintenance of growth throughout the growing season. The combined effects of new input and mixing during winter are illustrated by the silicate profile early in the spring of 1974 (Fig. 28). Vertical mixing elevates the surface layer concentrations to a fairly uniform 15 to 20 µg-at/ℓ compared to 2.5 µg-at/ℓ the previous summer. Direct contribution of river-borne silicate to the near surface samples contributes an additional >5 µg-at/ℓ to the top 10 to 20 m. The input of nutrients throughout spring and summer are harder to observe because of combined effects of biological utilization and regeneration in surface waters as well as inputs of fresh nutrients from underlying waters will all be recorded in the nutrient profiles.

Based on the physical mechanisms of runoff effects, freshwater regulation can affect these processes in several ways depending on whether increased runoff increases or decreases vertical mixing. During winter, additional mixing resulting from increases in freshwater inflow will combine with the added nutrient input of the freshwater to elevate surface concentration in the estuarine and Gaspé regions. In the open Gulf and over the Magdalen Shallows, increased freshwater inflow will increase the horizontal advection of nutrient rich water from the estuary but decrease the depth of mixing and therefore decreasing the amounts of nutrients mixed into the surface waters from below.

An additional effect of increased freshwater discharge during fall and winter may be an increased export of nutrients through Cabot Strait. Since biological activity is greatly reduced during winter, the cycling mechanism that traps nutrients within the Gulf will not be operating so increased transport out through Cabot Strait in winter will result in a loss of nutrients from the Gulf. Decreased freshwater discharge throughout the spring and summer will also affect the nutrient input to the surface by decreasing vertical mixing and upwelling thus reducing the upward supply of nutrients to surface waters. This will be combined with a decrease in the direct input of nutrients in the freshwater. The net effect of increased runoff in winter and decreased runoff in summer will be therefore to increase surface nutrient availability in early spring and decrease nutrient resupply to the surface layer through late spring and summer.

Possible changes in the effects of other chemical inputs or turbidity on biological production are expected to be minor compared to those of the nutrients. Since most of these inputs come predominantly from rivers, regulation effects that decrease depth of mixing and confine turbidity or toxic elements to surface waters would be the most important.

3.4 Interactions between Runoff and Biological Processes

3.4.1 Phytoplankton Dynamics

In a particular location, given non-limiting supply of light and dissolved nutrients, increases in phytoplankton standing crop will occur at a rate determined by the magnitude by which rates of growth exceed rates of removal by physical (vertical mixing and advection) and biological (respiration and grazing) processes. The critical importance of stratification in establishing this balance was recognized by Sverdrup (1954) who showed that when vertical density gradients reduce or prevent mixing of phytoplankton below the compensation depth, organic matter produced during photosynthesis exceeds loss through respiration, and a bloom may be initiated.

In temperate marine waters, it has been shown that the initiation of a phytoplankton bloom in early spring coincides with the onset of stratification (Riley 1956), but increased growth also requires sufficient incident radiation and a continuous supply of dissolved inorganic nutrients, particularly nitrate. Low temperatures do not inhibit photosynthesis.

Unless conditions of ice cover or turbidity limit light penetration, incident radiation even during winter is always sufficient in temperate latitudes to permit phytoplankton growth

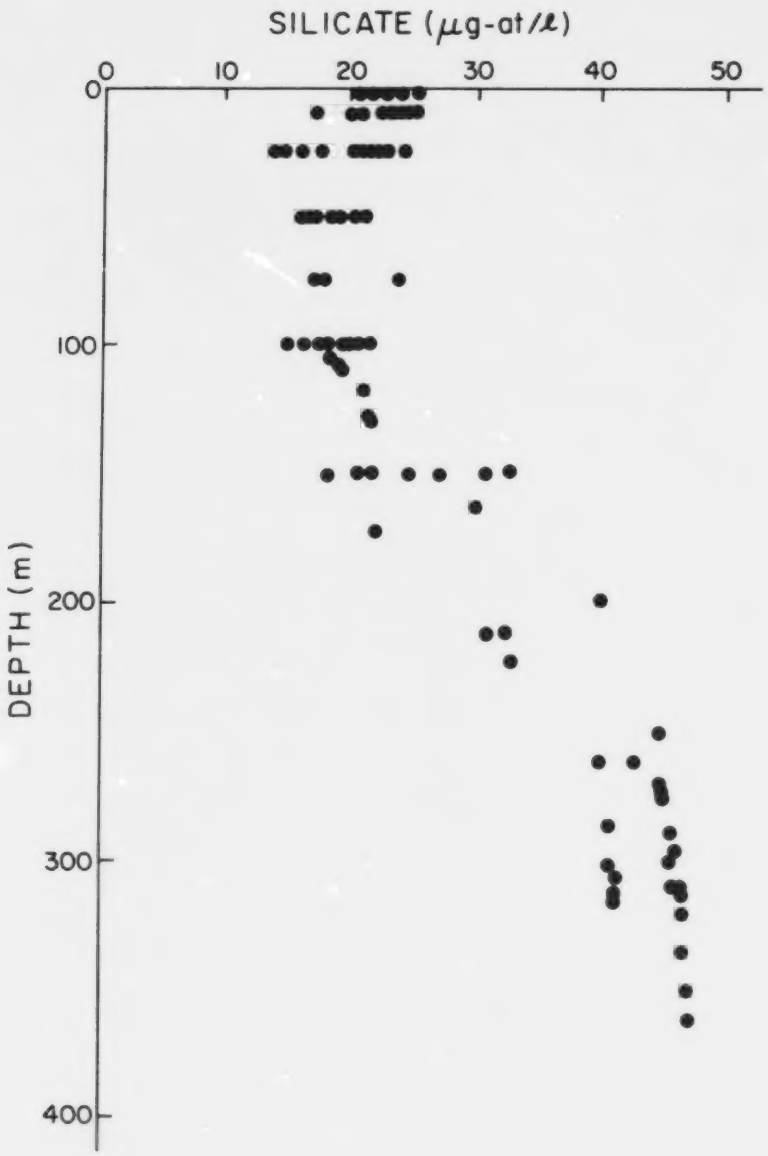

Figure 28 Composite silicate depth profile for the St. Lawrence Estuary (March 1974). (Unpublished data from A. Coote, Chemical Oceanography, BIO, Dartmouth, N.S.).

rates to equal or exceed loss through respiration. On the other hand, sufficient nutrient supply is usually assured through previous winter convective mixing. Even if conditions of light, nutrient supply and water column stratification are adequate for phytoplankton rapid growth, micro and macro herbivorous zooplankton may prevent bloom development by removal of increased biomass through grazing. But biomass of herbivorous zooplankton and their feeding rate, change markedly during the year in these latitudes, so that lowest numbers and grazing rates occur during winter months and early spring at the time of the onset of stratification. With these biological removal rates greatly reduced, the initiation and magnitude of phytoplankton primary production thus depend directly on light, stratification and nutrient supply conditions. Therefore runoff regulation will have an influence on primary production in as far as it can affect one of these three conditions. Likewise we should be able to distinguish the different regions of the Gulf of St. Lawrence system by observing the variations in the relative importance of these three factors.

Because the nutrient enrichment mechanisms described in section 3.3 are operating on a continuous basis, biological production is high in the Estuary (Steven 1975). It is also interesting to note that in spite of these high biological production rates, very low concentrations of nutrients (nutrient limitation) have rarely been observed in the surface waters of the St. Lawrence estuary (Sinclair et al. 1976; Therriault and Lacroix 1976; Greisman and Ingram 1977; Steven 1975; Coote and Yeats 1979). Therefore light and stratification conditions, and not nutrient supply, are the controlling factors for the biological cycles in this region of the Gulf system, and freshwater runoff regulation should be felt in as far as it can affect these two conditions. The dependance of short term temporal fluctuations in biomass and production on M_2 and M_f variations in the vertical stability of the water column have been clearly demonstrated by Sinclair (1978), Fortier and Legendre (1979), Demers and Legendre (1979) and Demers et al. (1979) for the St. Lawrence estuary. Sinclair (1978) observed that in spite of a marked stratification and a high daily radiation level, biological production was very low in early spring. This was related to the high turbidity of the lower salinity surface water occasioned by the increase of freshwater discharge. A sharp decrease in turbidity coincident with a decrease in freshwater input was immediately followed by a sharp increase in phytoplankton production. In brief, the main effect of freshwater runoff regulation in the Estuarine region of the Gulf system would be by influencing the timing of biological production events. This is achieved by determining stratification/turbidity conditions in the water column relative to the depth of the euphotic zone which enhance phytoplankton production. The overall intensity of biological production should, however, be more dependent on light availability than on freshwater discharge.

The second region under consideration comprises the frontal zone system (Tang 1980) and the Gaspé current which extends to the northern edge of the Magdalen Shallows. Within this area, biological biomass and production is considerably greater than in the rest of the Gulf (Steven 1975; Sévigny et al. 1979), being sustained by a continuous supply of nutrient-rich surface water coming from the Estuary and also benefiting from the upwelling process associated with the frontal zone and the along-front current described before. The difference in the seasonal characteristics of the biological production processes distinguishes the Gaspé current system from the Estuary. The Gaspé current is characterized by an early spring phytoplankton bloom, while no growth takes place in the Estuary before mid-summer. The high turbidity of the estuarine waters due to high freshwater runoff explains this difference. When estuarine surface waters reach the Gaspé current, their load of particulate matter has decreased considerably such that phytoplankton are less limited by light. Since the surface waters of the Gaspé current are continuously enriched, nutrient concentrations are nearly always well above the level considered limiting to phytoplankton growth. Thus the same factors that control biological production in the Estuary are in action in the Gaspé current, except perhaps, that freshwater runoff regulation has an additional effect by a direct influence of the intensity of upwelling in the frontal zone (Tang 1980).

The third region of the Gulf system includes the northwestern Gulf outside the frontal zone and the whole central and eastern parts of the Gulf, including the Magdalen Shallows. Throughout this large area, the annual cycle of biological production is determined mainly by vertical diffusion and mixing of nutrients in the water column in the same way as in other shallow marginal seas in temperate latitudes, modified to some extent by the presence of ice in the winter and spring. One would expect this region to be characterized by high rates of biological production in early spring which are brought to an abrupt end by nutrient exhaustion of the surface waters following thermal stratification and the establishment of a shallow summer thermohalocline. Annual biological production of this area is considerably lower than in the estuarine or Gaspé Current regions (Steven 1975; Sévigny et al. 1979) and is controlled entirely by

the stratification and, particularly, the nutrient supply conditions. As mentioned before, the effect of runoff can only be felt through modification in stratification in this extended region, an increase in runoff supressing mixing and vice versa. Therefore it can be assumed that the magnitude and duration of the phytoplankton standing stock achieved in the water column is determined by the size and rate of depletion of the pool of dissolved nutrients available above the stratification depth, within the euphotic zone.

The idea that the magnitude of phytoplankton standing crop formed during the vernal blooming period is determined by the reservoir of dissolved nutrients present prior to the onset of stratification has not been quantitatively examined. There are good reasons to believe that such a year to year relationship exists between these two variables. Although not based on phytoplankton data, the study of Southward (1980) relying on long term observations (55 years) in the English Channel implies such a relationship. Southward (1980) has observed a significant correlation between year-to-year fluctuations in maximum winter dissolved nutrient concentrations and the changes in abundance and species of zooplankton and of pelagic fishes. The causative factor behind those fluctuations was postulated to be a slight alteration in the water circulation pattern in the English Channel as a result of a cyclic climatic change.

Just as long term changes in advection and mixing in the English Channel may have caused variations in winter maximum nutrient concentrations, year to year differences in winter convective mixing, runoff discharge and ice cover could affect levels of dissolved nutrients in surface waters of the open Gulf of St. Lawrence. Increased winter runoff would have two main effects (1) to create surface density gradients and (2) to increase ice cover. These two effects counteract vertical transport through convective and wind mixing during the winter period and may prevent vertical mixing to reach deep nutrient-rich water.

Whatever the net result of these stabilizing and destabilizing processes, when stratification occurs, phytoplankton will deplete the nutrient reservoir present in the upper mixed layer. At greater depths, however, concentrations would remain high and be increased by sedimentation and regenerative processes below the mixed layer. Deep water masses may thus also show seasonal and year to year differences in dissolved nutrient concentration which reflect these differences in rates of vertical nutrient supply.

3.4.2 Fisheries Dynamics

Until there is a better understanding of how freshwater runoff affects plankton dynamics it is somewhat speculative to postulate mechanisms of possible freshwater effects on commercially exploited populations. It can however be stated again that for many fished stocks it has been concluded that year-class strengths are defined during the larval phase. Thus it is logical to conclude that if freshwater runoff variability has a major influence on plankton dynamics, and/or the physical oceanographic characteristics of the larval environment, that such affects should influence year-class strengths. Given the well-documented strong inter-annual variability in freshwater runoff into the Gulf, the relatively extensive data on southern Gulf cod, and the hydrographic time series for the Magdalen Shallows a relationship, if existent, should be observable.

The cod recruitment time series (1947 to 1976 year classes and 1957 to 1976*) were analysed in relation to RIVSUM and the Magdalen Shallow summer surface layer (0-10 m) temperature (May to September) and salinity (June). Cod recruitment was not statistically correlated with any of the temperature or salinity time series. There was a significant correlation with runoff the summer prior to spawning ($r = 0.62$ between shorter recruitment series and May + June runoff the previous summer). It is recognized however that the usual statistical confidence levels are not applicable when "high correlations" are being searched for. Nevertheless the "suggestion" that events the year prior to spawning may be important is consistent with (1) the finding that the number of oocytes are defined the year before spawning (K. Waiwood, Biol. Stn., St. Andrews, N.B., pers. comm.), and (2) Doubleday's (1981) conclusions that southern Gulf cod productivity is partially a function of RIVSUM.

For the longest marine fish data set there is not a strong case (in a statistical sense) to be made for the impact of freshwater runoff variability on year-class strength variability. There is however piecemeal evidence that is sufficiently intriguing to warrant further investi-

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* Less confidence in the earlier years due to scanty sampling and poor catch recording by area.

gation. There is some evidence that between year differences in freshwater runoff influence surface layer temperature and salinity over the Magdalen shallows. The greatest inter-annual variability in temperature is observed during the spring and autumn, whereas that for salinity is observed during mid-summer. In addition it is suggested that cod productivity is a function of RIVSUM and cod recruitment a function of RIVSUM the year prior to spawning when the number of oocytes are defined. There is no statistical suggestion however that winter runoff prior to spawning is important in defining cod recruitment (see page 54 for discussion of possible effects of winter runoff on summer plankton dynamics). In addition, from the published fisheries literature it has been concluded that Magdalen Shallows surface temperature (which is related to runoff) is important for mackerel spawning time (Lett 1979) and cod growth (Beacham 1981).

It was observed above (Section 2.4.2) that changes in annual lobster landings in separate regions of the Gulf of St. Lawrence show significant positive coherence over time. Synchronous patterns of changes in landings imply that some effects act on a broad geographic scale. Previous studies of lobster yield in Atlantic coastal waters have shown positive correlations between landings and winter temperature 6 to 8 years earlier (Dow 1969; Flowers and Saila 1972; Boudreault et al. 1977). Time lags involved in maximizing correlations imply that larval survival and growth are involved in causing the relationships. Excessively low winter temperatures are thought to be detrimental to newly settled larvae. Scarratt's (1964) year-to-year observations of lobster larval abundance in the Northumberland Strait do not show any simple relation to year-to-year changes in average winter temperature (taken as monthly means for surface temperature during December at Grande-Rivière, Appendix I). However lobster larval abundance was correlated with local river discharge during June and landings of adult lobsters with RIVSUM values for spring months 8 to 9 years earlier (Sutcliffe 1973). Both runoff and temperature thus appear to be of importance in determining lobster population size.

We have extended Sutcliffe's (1972) analysis of correlations between RIVSUM and annual lobster landings using annual values (without calculating running means) for the Magdalen Islands by calculating linear correlation coefficients between landings and RIVSUM for various hydrographic regions described in Section 2.4.2 (Table 7). Significant coefficients were obtained for all regions except Inverness, P.E.I. Gulf and Newfoundland - North Gulf. Historically landings in these regions have been relatively stable Fig. 29, 30). In contrast landings in the two other regions of Newfoundland (Fig. 29) and the Magdalen Islands (Fig. 30), which are more variable, are positively correlated with values of RIVSUM (Table 8). Maximum correlation coefficients, achieved by lagging RIVSUM a variable number of years, occur over a range of years which is not similar in all regions. Where correlations exist, maximum coefficients arise when landings are compared with RIVSUM from 3 to 9 years earlier. This is consistent with accepted age limits of lobsters harvested in all regions.

If river discharge into the Gulf of St. Lawrence affects lobster larvae by determining conditions for survival and growth, the influence need not be equivalent in all areas. Regions like Chaleur Bay and Northumberland Straits are directly influenced by discharge of the Miramichi and other smaller rivers. Runoff effects near the Magdalen Islands, however, are more likely to arise from discharge of the St. Lawrence River. We can offer no explanation for why landings in other regions (Inverness, P.E.I. Gulf, Newfoundland, North Gulf) show no relationship to RIVSUM. In contrast, landings along Newfoundland's South gulf and Atlantic coast are significantly correlated with RIVSUM but with a clearly different period of lag (3-5 and 8-9 years respectively) required to maximize correlation coefficients. Although no evidence exists, broad-scale long-term meterological events which affect runoff from the St. Lawrence River and Great Lakes drainage systems might also affect discharge into Hudson's Bay. Flow of freshwater from Hudson's Bay down the coast of Labrador would be delayed relative to that occuring directly from the St. Lawrence River.

Thus the combination of evidence that freshwater runoff is important in the Gulf of St. Lawrence heat budget, and that surface temperature and RIVSUM have been identified as important to fish biology, warrants detailed investigation.

4. SUMMARY AND CONCLUSIONS

The relative importance of freshwater runoff into the Gulf of St. Lawrence was put into perspective by looking at both the patterns of salinity distribution in the North Atlantic and the magnitude of annual river runoff in Eastern Canada. It has been concluded that low salinity (<32°/..) water from the Gulf of St. Lawrence covers the inner portion of the Scotian Shelf

Table 7. Correlation coefficients (r) for linear regressions of lobster landings (annual values for number of years given in parentheses) in various regions of the Gulf of St. Lawrence and average freshwater discharge from the St. Lawrence River (RIVSUM) with river discharge lagged from 0 to 13 years. Values underlined indicate that variables are significantly correlated with $p < 0.05$.

		Number of years lagged													
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Chaleur Bay (40)	0.03	0.10	0.24	0.41	0.43	0.64	0.58	0.44	0.32	0.50	0.34	0.03	0.21	0.28
2	Kent Co. (40)	0.02	0.08	0.13	0.28	0.32	0.43	0.39	0.27	0.25	0.19	0.02	0.20	0.17	0.17
3	Central Strait (40)	0.38	0.24	0.10	0.06	0.26	0.30	0.33	0.37	0.48	0.51	0.45	0.29	0.19	0.13
4	South Strait (33)	0.27	0.18	0.11	0.05	0.09	0.23	0.20	0.30	0.36	0.37	0.22	0.15	0.19	0.10
5	Inverness (33)	0.03	0.09	0.14	0.04	0.01	0.03	0.21	0.05	0.23	0.08	0.04	0.04	0.23	0.15
6	Magdalen Islands (40)	0.41	0.11	0.09	0.15	0.09	0.41	0.55	0.53	0.48	0.67	0.52	0.35	0.27	0.14
7	PEI Strait (23)	0.36	0.11	0.04	0.20	0.31	0.45	0.42	0.36	0.52	0.56	0.39	0.21	0.12	0.14
8	PEI Gulf (23)	0.25	0.24	0.30	0.24	0.10	0.20	0.11	0.12	0.17	0.13	0.16	0.13	0.18	0.17
9	Nfld.-North Gulf (27)	0.11	0.14	0.07	0.15	0.23	0.07	0.22	0.32	0.07	0.27	0.23	0.15	0.16	0.15
10	Nfld.-South Gulf (27)	0.27	0.37	0.53	0.74	0.69	0.68	0.61	0.49	0.41	0.29	0.12	0.19	0.33	0.53
11	Nfld.-Atlantic Coast (27)	0.59	0.43	0.14	0.07	0.15	0.18	0.33	0.49	0.73	0.74	0.62	0.54	0.37	0.12

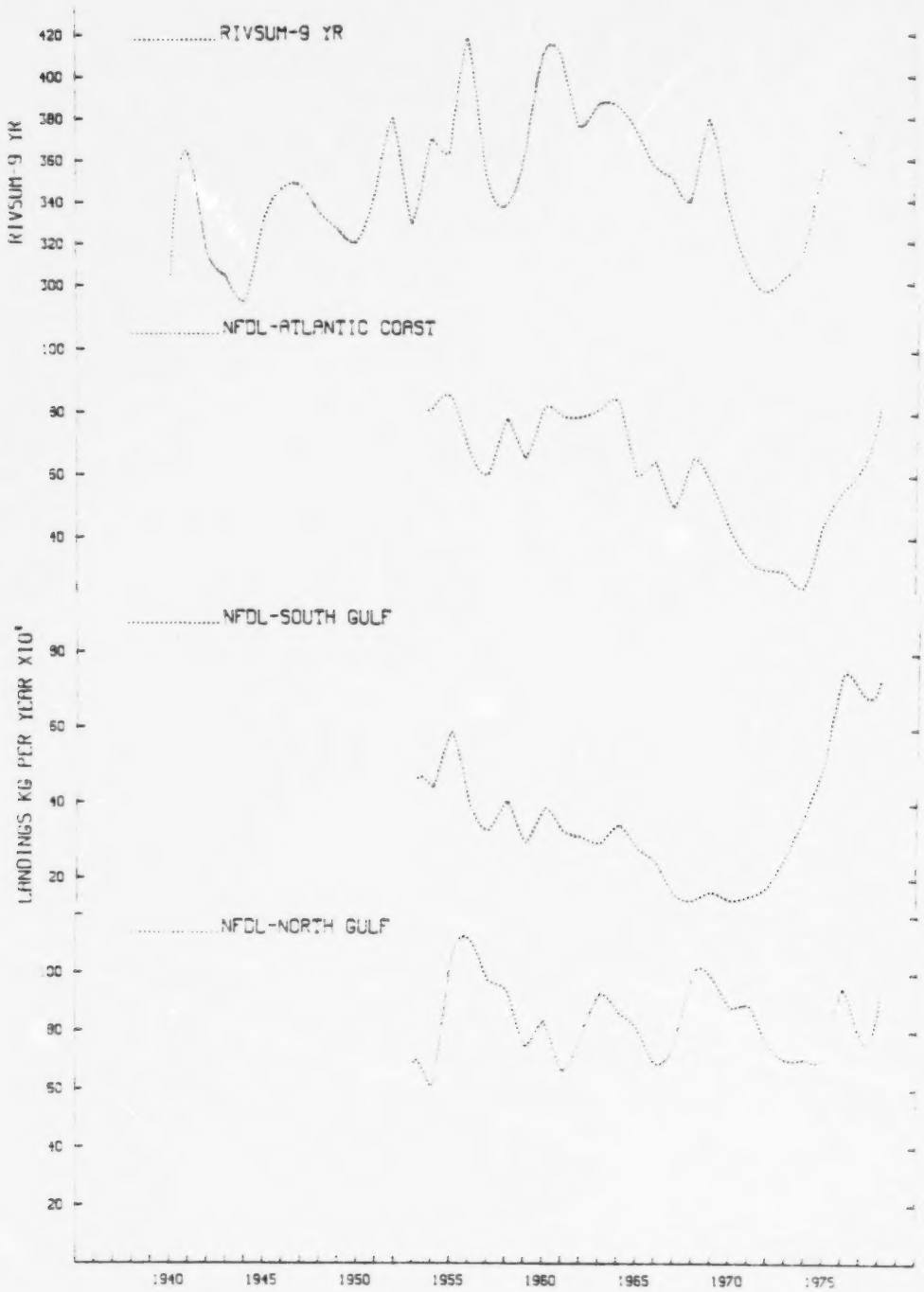

Figure 29. Time series of Newfoundland-Atlantic, South Gulf and North Gulf lobster landings and RIVSUM (lagged nine years). Annual values (summarized in Appendix II) taken as individual data points in each year drawn by a plotting routine.

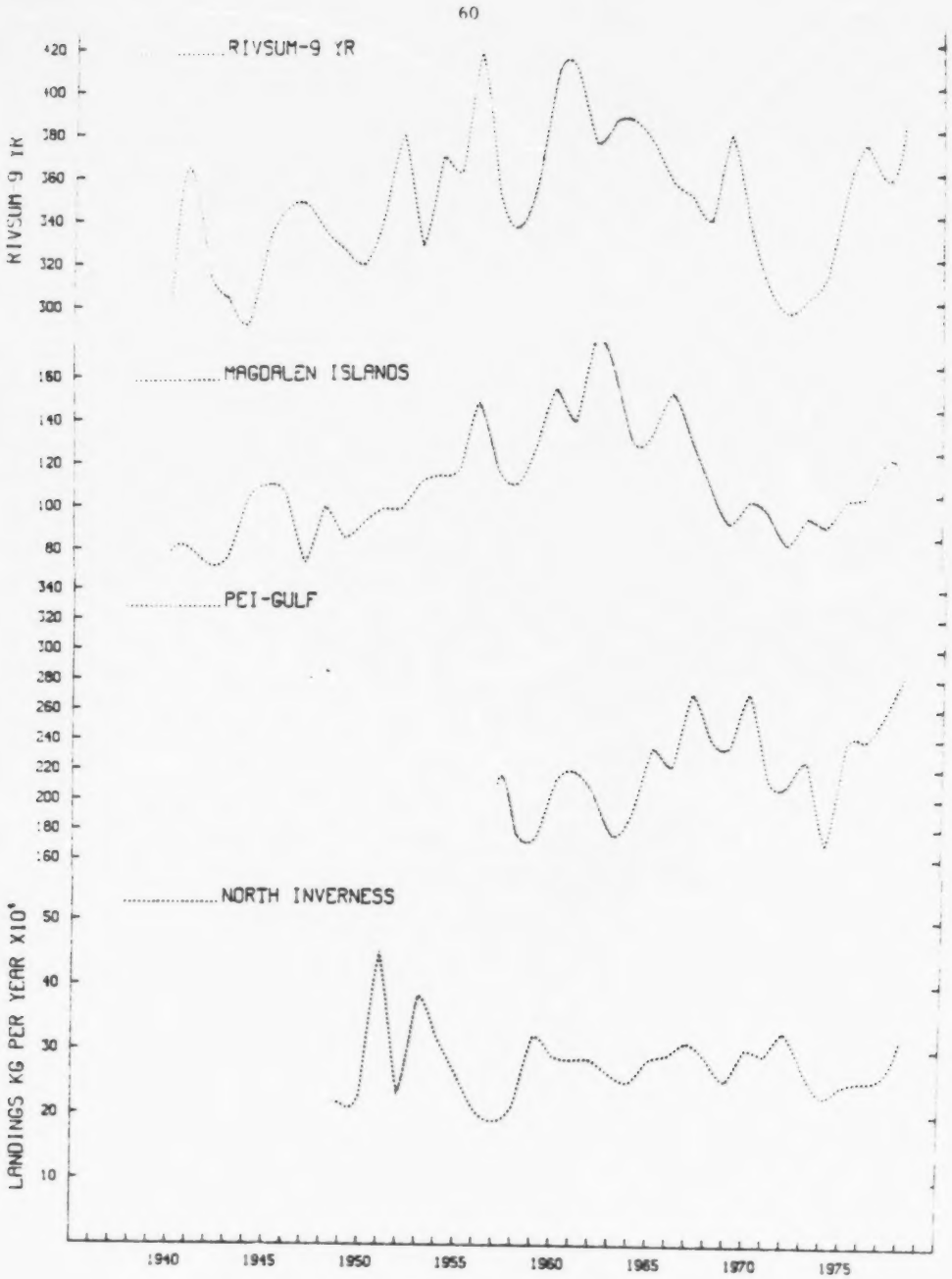

Figure 30. Time series of Magdalen Islands, PEI-Gulf and North Inverness lobster landings and RIVSUM (lagged nine years). Annual values (summarized in Appendix II) taken as individual data points for each year drawn by a plotting routine.

and that freshwater discharge through the Cabot Strait is a contributor to the along shore transport to the southwest over the inshore third of the Scotian Shelf. The St. Lawrence River system is a major contributor of freshwater into western Atlantic waters (424 km^3/year). The annual outward transport through the Cabot Strait has been estimated to be approximately 30 times the St. Lawrence River discharge.

The degree to which the Gulf of St. Lawrence can be viewed as an identifiable ecosystem was defined. The physical oceanographic characteristics support the idea that the Gulf forms an integral physical system. The features include the prominent intermediate cold layer, relatively restricted exchange of water through the Belle Isle Strait, an estimate of residence time on the order of a year and an 'estuarine' type density driven circulation which may permit extensive vertical transport of salt and nutrients. Nutrients in the deep layer of the Gulf are three times as high as concentrations in the North Atlantic outside the Gulf. The literature reports of high phytoplankton production were noted, but not accepted at face value. Plankton and benthos characteristics, except for the low species richness of zooplankton, were not different than that observed in contiguous waters. There is, however, convincing evidence from fisheries research (including definition of stocks, biomass trends, species composition and their rank order and relative year-class strengths) that many of the Gulf of St. Lawrence fish populations are limited to the Gulf for the critical parts of their life cycle.

From both an oceanographic and fisheries viewpoint the Gulf of St. Lawrence can indeed be viewed as an identifiable ecosystem. To a large degree one might expect interannual differences in its features to be a function of internal events rather than a result of large scale oceanic processes.

The diverse data sources that are available to determine the effects of freshwater runoff regulation on the Gulf of St. Lawrence ecosystems were reviewed.

There have been dramatic changes in freshwater storage of the St. Lawrence River and other parts of the Gulf of St. Lawrence drainage basins during the past two decades. The present resevoir capacity of 70 km^3 for the St. Lawrence drainage system is approximately 15% of the annual discharge (424 km^3). The more recent discharge data for the St. Lawrence system (RIVSUM) was described (from 1940 to the present). Interannual variability in the freshwater runoff was evaluated. The coefficient of variation (s/x) of RIVSUM annual mean runoff (1950 to 1979), which is relatively little influenced by regulation, is 10%. The maximum level observed in 1974 is approximately 50% higher than the minimum in 1963. It has been estimated that the peak in summer discharge from the St. Lawrence system has been reduced by between 15 to 35% due to regulation. It may be concluded that the regulation effect is of the same order of magnitude as the interannual variability.

Daily water level data are available for a variety of shore stations within the Gulf since the turn of the century. Since the time series begins well before large scale regulation, it may permit evaluation of the effect of variable runoff on certain physical processes. A few selected time series of water level were analysed in relation to discharge from the St. Lawrence system. Even though the estimated mean transport of freshwater at Pointe-des-Monts is well correlated with the water level data at Québec City ($r = 0.93$), there is no clear relationship between freshwater discharge and annual mean water level at other stations at increasing distances from Québec. The monthly mean water level differences across the estuary were analysed for two pairs of stations (Rivière-du-Loup/Tadousaac and Pointe-au-Père/Baie-Comeau) in relation to variable discharge levels. There was no apparent correlation or pattern in the results. This suggests that either freshwater runoff does not have a dominant effect on surface currents within the estuary, or that the simple water level analysis attempted in this report does not adequately reflect the surface currents. It could not be concluded that surface currents as reflected by water level in the lower St. Lawrence Estuary are strongly influenced by interannual differences in runoff, or its regulation.

Gulf of St. Lawrence water temperature data from both shore stations and the MEDS bathythermograph and 'bottle' data base were analysed. The Gulf was divided into three regions: the Magdalen Shallows, the Northeast Gulf and the Northwest Gulf. The average temperature over the top 10 metres was compiled on a monthly basis for each of the three regions from 1944 to 1977 for the months May to November. It was concluded that the surface layer data should be sufficient to examine the relative importance of various factors controlling the physical characteristics of the mixed layer. It was noted that there is some coherence with respect to autumn surface layer temperature between the three regions of the Gulf, but a lack of coherence for spring and summer months.

Interannual variations in several parameters characterizing the intermediate cold layer were calculated. Values for the depth of the temperature minimum, the value of the temperature minimum and the upper and lower depths of the 1.5°C isotherms were compiled for the years 1951 to 1975. It was expected that this data might be useful in determining which factors control winter-time convection and ice formation.

Salinity data for the Gulf is available from the MEDS bottle data. The data was treated in the same manner as that for temperature. Estimates of the mean surface layer salinity were not considered to be as accurate as the temperature estimates due to the smaller number of observations (the temperature estimates being derived from both BT and bottle data) and the larger horizontal gradients. A limited set of nutrient data covering the years 1969 to 1975 exists for the Gulf. The seasonal coverage as well as the length of the time series is much poorer than that for temperature and salinity.

The best time series data of phytoplankton biomass estimates are from the Lower St. Lawrence Estuary. By combining all available data in this region, six years of seasonal observations between 1969 and 1980 were described. Large interannual differences in chlorophyll concentrations are observed, which are not readily interpretable. Winter data are completely missing. There is no time series data at all for zooplankton.

Even though there are no time series observations on benthic invertebrate populations within the Gulf of St. Lawrence it has been concluded that fluctuations in annual commercial landings of lobsters may reflect natural population fluctuations. This assumes that fishing effort has been constant over the period of interest. Even though landings back to the turn of the century are available, they are only reported by the present statistical districts since 1947. The landings data since 1947 were analysed on a regional basis (rather than statistical district) to combine areas which were considered to reflect different recruitment units. Annual landings in 23 out of 55 comparisons were significantly correlated. Areas within the Northumberland Strait demonstrated the greatest coherence for year-to-year changes in yield. The coincidence in trends of lobster landings between some areas within and outside the Gulf was felt to give some support to the view that factors affecting lobster landings (or population size) act in a widescale manner.

It was not felt that the assumption of constant effort could be made for finfish landings. Thus only the time series of catch-per-unit of effort, research vessel abundance estimates and the results of cohort analyses were considered useful indicators of population fluctuations. The latter analyses provide estimates of both stock biomass and year-class strengths. The best time series is for southern Gulf of St. Lawrence cod (cohort analysis from 1950 to the present). The results of recent assessments indicate considerable year-class parallelism within each of the two cod and herring management units in the Gulf on each side of the Laurentian Channel. This suggests that the factors influencing year-class strengths act on Gulf wide scale.

The limitations of the data sets for evaluating the effects of freshwater runoff regulation were considered. The effect of regulation on the seasonal runoff itself is well documented. There is some time series information on physical characteristics of the Gulf and on a limited number of commercially exploited populations, but essentially nothing in between. The limitations imposed by the available data delimit the analyses and conclusions that can be made in this report.

The limited empirical observations described above, and theoretical considerations on the processes involved, were used to assess evidence for the effect of regulation on the Gulf of St. Lawrence ecosystem.

Within the lower St. Lawrence Estuary it is inferred that, if all other factors are held constant, an increase in river inflow will increase the horizontal mass and salt transport. It is noted that the predicted increased transport during high runoff years was not reflected by the water level data. Within the St. Lawrence Estuary, because of the many factors contributing to the variability of horizontal salt and mass transport and a lack of long time series of oceanographic data, no conclusion about changes in transport as a result of increase or decrease in runoff can be drawn. An analysis of water level data showed no correlation between the surface currents and the discharge. This serves as a hint that factors other than runoff, such as wind, may be more important in determining the inflow-outflow structure of the estuary than runoff itself. It is not clear how variable runoff influences upwelling at the head of the Laurentian Channel.

At the head of the Gaspé Current it has been concluded from a model study that the rate of frontal upwelling in this area should increase with along-front horizontal volume transport. Therefore frontal upwelling should be directly related to freshwater runoff. Downstream of the Gaspé Current in the Magdalen Shallows it is concluded that an increase in runoff is expected to suppress mixing (due to the greater importance of increased stratification relative to increased shear expected to occur in this area). Conclusions concerning the effects of variable runoff on the northeastern Gulf and on transport out of the Gulf through the Cabot Strait were not drawn.

From the empirical data it was observed that during high runoff years the surface layer salinity over the Magdalen Shallows decreases by one part per thousand. This gives some support to the conclusion that entrainment is not directly proportional to runoff. It should be noted that increased runoff, even though it may suppress mixing, may still result in a greater absolute vertical entrainment of salt (and nutrients). The relationship between entrainment and runoff would be expected to be non-linear.

An attempt was made to quantify the effects of a decrease in river discharge in the spring on the buoyancy flux to the surface layers of the western Gulf. It was estimated that freshwater discharge and surface heat flux are approximately equally important in so far as surface buoyancy flux in April is concerned. The effect of regulation on the western Gulf surface temperature for the months of April and May was estimated. A surface layer temperature decrease due to regulation of up to 0.5°C was estimated. Although the calculation is rough, it is concluded that freshwater regulation has had a significant effect on the temperature of the waters in the southern Gulf through changes in the depth of the mixed layer. The effect of increased winter discharge due to runoff regulation was considered. A correlation of -0.73 between the estimated depth of the lower 1.5°C isotherm and the winter freshwater discharge suggests that the variation in fall and winter discharge (due to both natural interannual variability and regulation) have had an effect on the depth of vertical mixing.

If the above inferences and conclusions concerning the effect of freshwater runoff variability on physical processes in the Gulf are correct, some inferences can be drawn relative to nutrient transport. During winter the increased mixing (induced by higher runoff due to regulation) should result in elevated surface nutrient concentration in the Lower Estuary and in the Gaspé Current. In the open Gulf and over the Magdalen Shallows, however, it is postulated that the increased winter discharge due to regulation will increase advection of nutrient rich water from the estuary but decrease the depth of mixing downstream (due to the greater stratification) and therefore decrease the amounts of nutrients mixed into the surface waters from below. An additional effect of increased fall and winter discharge may be increased export of nutrients through the Cabot Strait. Decreased discharge in the spring and summer due to regulation is postulated to result in decreased mixing and entrainment in the estuary and Gaspé Current, but possibly greater vertical nutrient transport downstream of these areas due to the reduced stratification.

The response of phytoplankton production to the regulation induced changes in the physical environment and nutrient dynamics is expected to vary geographically. In the estuary, where phytoplankton growth is rarely nutrient limited, the decreased discharge in the summer months is expected to modify the stratification/turbidity conditions which should influence the timing of bloom-formation. The predicted decrease in along frontal upwelling and nutrient entrainment in the Gaspé Current due to regulation should, however, result in decreased summer production.

Downstream of this area over the Magdalen Shallows the phytoplankton response is more difficult to predict. The increased winter discharge is postulated to result in a decreased reservoir of dissolved nutrients prior to the onset of seasonal stratification and vernal blooming (and as a consequence a smaller spring bloom). However the decreased spring/summer discharge may result in increased entrainment of nutrients due to the reduced stratification. The relative importance of the initial nutrient reservoir during winter and early spring and the summer additions due to entrainment and mixing determine whether regulation would enhance or diminish overall primary production.

The causal arguments developed above (from regulation to physical processes in receiving waters to surface nutrient fluxes to primary production) cannot be developed further up the food web. From correlation analyses between lobster landings and RIVSUM it has been inferred in the literature that runoff variability controls recruitment to some of the adult stocks. The oceanographic processes involved, however, have not been identified. This review has not made

progress in this direction, other than inferences concerning the primary production drawn above. Correlation analyses were extended to include a broader geographical area of lobster landings. Significant correlations between landings in all regions (except Inverness, PEI Gulf and Newfoundland North Gulf) and RIVSUM were obtained (with a variable lag).

A similar approach was taken with the finfish time series of year-class strengths (southern Gulf of St. Lawrence cod). From the statistical analysis there was not strong evidence that freshwater runoff (as reflected by RIVSUM or Magdalen Shallows surface temperature and Salinity) is important to year-class strength definition. It has been suggested that cod productivity is a function of RIVSUM, and a significant correlation was obtained between cod recruitment and RIVSUM the year prior to spawning when the number of oocytes are defined. As is the case for the lobster correlations, the statistical inferences are of interest but they do not readily permit the identification of the critical processes.

5. RECOMMENDATIONS

An assessment of effects of freshwater runoff regulation in the Gulf of St. Lawrence must depend on the questions which are asked. It is neither feasible nor necessary to study all interactions between runoff and physical, chemical and biological processes until specific questions are posed. Effects of freshwater discharge on any marine environment are complex and interrelated with other factors, such as meterological forcing. It is also important to emphasize that natural year-to-year variation in runoff may mask effects due to discharge regulation. Existing data sets cannot be examined to assess effects of discharge regulation since the major sources of freshwater (the St. Lawrence and Saguenay Rivers) have been regulated before an adequate data base of oceanographic information existed. We are left then, except in the case of the remaining North Shore rivers, to utilize the natural variations in freshwater discharge to determine governing mechanisms of the system and then extrapolating to pre-regulation conditions using our knowledge of these mechanisms.

Freshwater runoff is one of many factors causing the variation in the water level in the St. Lawrence Estuary. A more in-depth analysis of the water level data base could be undertaken to determine the relative contribution of runoff to the variability of the water level and thus perhaps the surface currents. The preliminary analysis in this report using data from 1961 was not confirmatory. A more detailed analysis with water level data from as early as possible (1908) and meteorological data might show historical changes in water level which could be related to increased reservoir storage.

It has been shown from observations that upwelling and intense mixing occur in the frontal zone (including the Gaspé Current) of the northwestern Gulf. Since the front is known to be a result of the outflow of the low salinity water from the estuary, a change in the runoff should affect the rate of upwelling. The model result that an increased along-front horizontal volume transport induces a higher rate of upwelling should be verified, and the relationships between runoff, upwelling and productivity should be established. Oceanographic characteristics of the frontal zone should be monitored in relation to runoff variability (in order to quantify the plankton production response to the physical variability). A program utilizing both ship measurements and remote sensing data should be established to study the seasonal as well as the long term variation in the position and distribution of properties of the frontal zone. Properties to be measured include stratification, turbidity, dissolved nutrient concentrations and phytoplankton biomass and production.

In the open Gulf, particularly the Magdalen Shallows, it has been concluded that an increase in runoff is expected to suppress mixing (and entrainment), due to the greater importance of increased stratification relative to increased shear. The relative importance of the stratifying influences of freshwater discharge, surface heat flux, solar radiation and wind mixing (in creating and modifying characteristics of the surface mixed layer in the open Gulf) should be evaluated. An adequate data base already exists to evaluate the effect of variations in freshwater discharge on the surface mixed layer over the Magdalen Shallows during the late spring to early autumn period.

In deeper water in the open Gulf there are not sufficient data to analyze the inter-annual differences in the breakdown of the surface mixed layer and associated vertical convection driven by surface cooling during late fall and early winter. Since this process is to a large extent responsible for the formation of the intermediate cold layer, which appears to be the source of the upwelled and entrained water during the stratified months, its characteristics warrant further study.

It is also hypothesized that the depth to which winter convective mixing extends depends on the balance between mixing due to the severity of winter winds and the stratifying influence of freshwater runoff. Deeper winter mixing should enrich the surface layer with dissolved nutrients so that when stratification occurs in the spring, the size of the phytoplankton bloom is proportional to the size of the dissolved nutrient pool available and level of solar radiation. Almost no measurements of dissolved nutrients have been made during late winter (February-March) to test the idea that changes in freshwater runoff affect the size of the nutrient pool present in surface waters in early spring. We must also investigate the dependence of the phytoplankton biomass (during the early spring bloom and on an annual basis) on annual variations in solar radiation. A program over several years, during late winter, to measure vertical profiles of nutrient concentrations, salinity, temperature and solar radiation at various locations in the Gulf should be established.

Even though it was concluded that there is not a linear relationship between runoff and entrainment, the form of the relationship (for example, whether it is dome shaped or asymptotic) is not known. That the nature of the relationship between runoff and entrainment in various areas of the Gulf should be investigated. It is recognized that this recommendation overlaps somewhat with the first four. A modelling approach aimed at evaluating the relative importance of the factors controlling vertical transport of salt (and nutrients) in the various areas of the Gulf is recommended. The model should also be used to assess the relative importance of various factors controlling the horizontal transport out of the Cabot Strait.

Assuming that the physical processes and their sensitivities to runoff have been realistically described, some inferences have been drawn concerning the response of phytoplankton production to the regulation induced changes in the physical environment. It has been concluded that the production cycles in four areas of the Gulf should differ substantially. The seasonal plankton production cycles, both primary and secondary, and their sensitivity to runoff induced physical processes in four hydrographic regions (the lower estuary, the Gaspé Current, the Magdalen Shallows and the Northeast Gulf) should be more adequately described. If we are to consider the role which freshwater discharge plays in determining the distribution of dissolved nutrients and phytoplankton biomass and production throughout the year in the Gulf, it is essential that time series monitoring stations be established to quantify temporal variation. Sampling programs should be established in each of four areas to provide vertical profiles of temperature, salinity, dissolved nutrients, chlorophyll a, particulate organic carbon and a measure of phytoplankton production. Sampling frequency should be twice per week throughout the year. If ice conditions make these measurements impossible, shore-based stations could provide supplementary data. Cross-estuary ferries may also be suitable sampling platforms if the duration of sample collection is kept short. Monitoring should extend over a period of time (up to ten years) to ensure that inter-annual variation in freshwater discharge would occur.

A parallel monitoring program should be established to consider site-specific (spatial) effects of freshwater discharge. This project would involve studies in the plume region of one river (perhaps along the North Shore of the Gulf) subject to regulation at least five years from the initiation of the study. Observations of temperature, salinity, dissolved nutrients and chlorophyll distribution horizontally and vertically within the plume would be made intensively at selected times of the year (seasonally perhaps) for each of five year periods before and after discharge regulation. The observations of the structure of the plume and its dependence on the magnitude of freshwater discharge would be localized. However, an understanding of mixed-layer dynamics and resulting phytoplankton growth would be of general value.

The causal arguments (from freshwater regulation to physical processes in the receiving waters to surface nutrient fluxes to primary production) could not be developed further up the food web. However year class parallelism between stocks of fin fish species and Gulf-wide coherence in trends in annual lobster landings in many areas, imply that factors creating oceanographic features within and perhaps outside the Gulf operate in a wide-spread manner. Runoff has also been inferred as an important factor from statistical analyses.

Two types of studies should be carried out at higher trophic levels in relation to determining the effects of natural runoff variability and its regulation on population biology of selected species. The first category involves detailed descriptions of the distributions at various stages of the life history (egg, larval, juvenile and phases of the adult annual migration) for selected commercially important stocks in the Gulf of St. Lawrence. In some cases this can be largely done using existing data (eg. 4TVn Cod) but in other cases new sampling studies are needed (eg. 3P4RS cod egg and larval distributions are unknown). Detailed distributional studies of lobster larvae in relation to current hypotheses concerning biological stocks and recruitment cells within the Gulf are also recommended. From such fundamental distributional studies, specific proposals for observations can be made which assess the relative importance of parental stock size and climatic factors in determining year-class strength (as recommended by Akenhead et al. 1979). A second category of studies involves population processes rather than distributional studies. Growth line studies should be carried out to correlate periodicity in growth checks with changes in river discharge. Long lived mollusc species (such as Artica) should be examined to document annual growth rates in individuals from different areas within and outside the Gulf. This would permit a direct test for synchrony in growth in different areas.

No conclusions were drawn related to ice formation and distribution in the Gulf in relation to runoff, however this question seems of sufficient importance to merit specific research. The effect of excess stratification during winter, caused by high runoff during previous months, may profoundly influence the rate at which ice can be formed in the Gulf. Observations of ice cover are extensive but rather qualitative in nature and these should be quantified. Ice forecast cruises which have been mounted over the past 20 years in November and early December should be continued. They provide data which requires further analysis in relation to ice conditions.

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Appendix I.

Government publications of river discharge data for Québec.

1908-1963 Water Resources Paper series by Water Resources Branch, Department of Northern Affairs and National Resources.

On April 1, 1964, the Ministère des Richesses Naturelles du Québec assumed responsibility for the hydrometric survey investigations concerning most Québec rivers. The federal government continued to operate a network of strictly federal hydrometric stations in Québec in the interest of navigation in inter-provincial and international waters.

1964-present Provincial Station: Data are published in Annuaire Hydrologique by Service de L'hydrométrie, Ministère des Richesses Naturelles, Government du Québec. English translation of this report (1964-1968 only) was published by the Water Resources Branch of Environment Canada.
Federal Stations: 1964-1974, data were published in the Surface Water Data publication for Ontario by the Water Resources Branch.
1975-present, separate publication for Québec.

These data publications tabulate daily discharge rate or water level and give pertinent information about the hydrometric stations such as location, drainage area, gauge type and period of record. At storage dams, monthly storage change as well as outflow are recorded from which natural discharge can be computed. In 1972, 1974, 1976 and every three years since, the Water Resources Branch has published a series titled "Historical Streamflow Summary", which contains a summary of historical monthly and annual mean discharges for all federal stations where five or more years of data have been obtained. A summary of historical water level data is contained in another series titled, "Historical Water Levels Summary" which was first published in 1978 and will be published at three-year intervals.

Appendix II.

Time Series Data

Solar Radiation (Kentville) - Atmospheric Environment Service

Air Temperature (Gridstone Island) - W. Sutcliffe

Northeast Gulf 0-10 m Temperature - MEDS (Bugden)

Northeast Gulf 0-10 m Temperature - MEDS (Bugden)

Magdalen Shallows 0-10 m Temperature - MEDS (Bugden)

Grande Rivière Surface Temperature - (Sutcliffe)

Entry Island Surface Temperature - (Sutcliffe)

Characteristics of Intermediate Cold Layer - MEDS (Bugden)

Northeast Gulf 0-10 m Salinity - MEDS (Bugden)

Magdalen Shallows 0-10 m Salinity - MEDS (Bugden)

Gulf Rivsum - W. Sutcliffe

Lobster Larve (Northumberland Strait) - D. Scarratt

Lobster Landings (Gulf of St. Lawrence) - D.G. Robinson and G.P. Ennis

Gulf Finfish Biomass Indices - M. Sinclair

SOLAR RADIATION - KENTVILLE (AES)- MONTHLY DAILY MEANS (g-cal. cm^{-2})

	January	February	March	April	May	June	July	August	September	October	November	December
1960				473	491	533	517	508	356	235	116	91
1961	139	214	297	321	454	526	515	454	334	194	120	84
1962	139	212	319	378	495	498	388	373	297	203	119	107
1963	119	203	328	359	470	561	510	395	306	239	99	99
1964	116	205	296	415	503	474	453	457	384	198	147	86
1965	121	228	342	411	474	590	548	485	399	239	137	101
1966	102	221	317	425	486	527	561	474	382	241	127	93
1967	128	217	315	423	398	521	475	442	367	210	142	114
1968	141	246	279	392	489	459	572	533	336	218	108	84
1969	121	148	304	371	458	526	513	442	312	221	106	77
1970	134	197	291	373	459	487	505	403	276	225	130	98
1971	128	203	299	337	416	560	505	433	355	245	124	96
1972	120	229	247	334	504	462	461	468	324	183	105	81
1973	121	180	324	339	341	477	447	398	357	211	115	78
1974	110	195	314	311	381	510	453	444	269	232	101	73
1975	110	189	263	343	404	522	480	412	320	221	150	85
1976	102	168	306	345	453	515	453	455	282	213	116	99
1977	135	181	276	405	518	361	532	433	322	209	147	79
1978	102	221	327	351	522	501	501	489	369	169	150	91
1979	93	174	294	341	395	517	497	350	401	171	109	89

AIR TEMP GRINDSTONE ISLAND (MONTHLY MEANS)(°C)

	January	February	March	April	May	June	July	August	September	October	November	December
1940	-9.17	-9.28	-3.67	-0.33	5.44	10.44	14.44	16.83	13.00	5.78	2.06	-4.72
1941	-8.00	-6.67	-5.78	0.11	4.78	10.00	15.50	13.11	9.94	5.83	1.50	-2.67
1942	-8.22	-7.72	-2.28	1.06	7.56	12.28	17.00	17.22	14.33	9.11	2.00	-6.00
1943	-10.44	-6.67	-5.72	-0.28	4.56	9.17	16.00	16.17	14.61	9.78	3.06	-4.67
1944	-6.61	-8.39	-5.78	0.00	6.72	11.50	16.56	18.39	14.72	7.22	3.72	-2.78
1945	-3.94	-5.78	-3.56	1.78	5.33	10.11	16.89	18.39	13.78	7.72	2.28	-3.28
1946	-7.50	-8.61	-2.61	-0.22	6.11	12.17	15.61	17.61	14.94	9.50	2.00	-3.56
1947	-8.28	-5.17	-3.17	-1.83	5.17	10.50	18.83	17.56	13.33	8.61	3.00	-2.67
1948	-5.44	-11.44	-7.22	-0.56	5.50	10.44	16.17	17.17	13.33	8.72	4.56	-1.22
1949	-6.72	-8.17	-2.49	0.44	6.17	12.44	17.61	16.61	13.17	9.00	2.22	-0.83
1950	-6.89	-11.33	-6.50	0.44	7.39	12.61	16.39	16.72	12.44	7.61	4.89	0.28
1951	-6.06	-4.17	-1.33	4.17	6.83	11.72	17.33	17.17	14.50	8.22	2.83	-3.17
1952	-9.28	-4.33	-2.00	1.22	6.33	11.33	18.11	18.78	14.56	7.56	2.11	-1.94
1953	-3.44	-4.33	-3.11	3.22	5.72	11.89	16.78	15.78	13.56	7.39	4.44	-0.72
1954	-6.22	-5.44	-5.44	-0.67	5.50	11.00	16.11	14.33	12.44	7.50	2.67	-0.67
1955	-2.67	-4.50	-6.28	0.39	5.50	11.22	16.89	16.83	12.06	7.61	2.33	-4.39
1956	-1.56	-5.89	-5.39	0.61	4.11	10.67	15.22	16.11	12.39	7.61	2.83	-3.50
1957	-10.61	-8.33	-5.67	-0.28	4.89	10.78	15.83	16.11	13.22	8.17	3.56	-0.33
1958	-2.22	-3.17	-0.78	2.61	6.72	10.44	15.72	16.83	12.33	7.11	1.94	-6.50
1959	-6.50	-11.11	-5.53	1.06	6.22	9.83	17.39	16.22	13.39	7.06	3.28	-1.56
1960	-9.17	-9.00	-2.83	0.39	7.89	12.89	17.06	17.89	13.50	7.17	3.22	-2.28
1961	-9.00	-10.89	-6.50	-0.11	5.17	11.78	16.11	17.61	15.11	9.72	4.89	-0.89
1962	-6.72	-11.17	-2.44	1.00	4.89	10.94	12.94	16.00	12.50	7.89	3.61	-2.50
1963	-3.39	-9.50	-6.11	-0.67	6.83	11.06	16.67	15.61	11.56	9.11	4.11	-4.78
1964	-6.28	-6.22	-4.39	-0.28	5.72	10.50	15.33	15.89	12.50	7.39	1.33	-2.61
1965	-6.72	-8.22	-4.28	-0.61	4.89	11.22	16.50	16.83	12.06	6.61	0.39	-3.33
1966	-5.61	-6.33	-1.67	0.72	5.94	12.11	16.33	17.61	12.67	7.61	4.33	-0.56
1967	-6.50	-9.00	-0.11	-2.06	3.33	12.56	18.94	19.50	13.67	8.56	3.39	-2.06
1968	-7.00	-9.00	-3.78	1.83	6.11	10.44	17.06	14.89	14.56	9.83	1.89	-1.33
1969	-3.17	-3.56	-2.69	0.11	5.61	12.61	15.44	17.17	12.94	6.72	4.72	0.83
1970	-7.61	-6.67	-3.56	0.28	6.72	12.33	17.78	18.33	11.33	8.89	4.06	-4.22
1971	-6.78	-7.06	-2.39	1.28	7.06	11.39	16.94	17.28	13.28	8.06	2.33	-4.28
1972	-7.28	-10.72	-4.28	-1.83	5.17	11.56	15.94	15.72	12.39	6.22	1.06	-6.06

NORTHEAST GULF 0-10 m TEMPERATURE (BATHYTHERMOGRAPH) (°C)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1944					14.1	9.5	5.4
1945					14.7		
1946							
1947			13.0	15.8			5.4
1948		5.2				8.5	7.0
1949			12.5				5.8
1950		6.5	12.4		13.7		2.4
1951	3.3	9.1	14.0	15.1	12.1	11.2	
1952	2.0	7.2	12.3	15.8	13.1	9.2	6.2
1953		4.9	12.0			8.2	
1954		7.1	11.1	12.2	8.2	7.4	
1955		7.5	13.6	13.8	9.6		4.3
1956	0.4	4.3		14.6			4.2
1957		4.6	11.2	14.4			4.8
1958		6.9	11.6		13.1	7.3	
1959		6.2	11.6			7.5	4.7
1960		7.2		16.8	11.3		5.2
1961	2.7	8.4	12.2	17.4	13.6		5.7
1962	1.9	6.6	11.4	16.7	14.7	8.3	5.6
1963		7.4		16.1	10.7		5.5
1964				14.7	11.2		3.9
1965		7.7	13.2	17.5	14.1	9.3	3.9
1966		6.9	12.7	16.0		8.3	5.2
1967	1.0		12.3	14.7		10.4	5.1
1968	2.2	6.5				9.4	5.5
1969	2.5	6.1		13.8	11.0		5.6
1970	2.4	5.8	12.0	15.6	13.5	10.3	
1971	3.8				10.9		
1972	1.0	3.6		14.1	11.8	6.1	2.7
1973	1.5		13.2	16.3		7.2	3.3
1974	1.9	6.0		14.1			3.3
1975					13.1	7.6	
1976				17.3		6.8	2.9
1977					10.6		

NORTHWEST GULF 0-10 m TEMPERATURE (BATHYTHERMOGRAPH) (°C)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1944					11.1	6.9	4.5
1945					14.0	8.5	
1946					10.3	5.7	
1947					8.4		4.4
1948		6.2				8.9	
1949			13.7				3.9
1950		8.3	11.6		12.2	4.8	2.4
1951			14.4			2.9	2.7
1952	2.3	8.0	13.1		10.9	4.8	
1953		8.0	10.0	11.2	9.5	7.2	
1954		7.2	11.4		10.1	5.8	
1955		10.6		14.0			
1956	0.8	6.5	13.9	12.4	10.2		2.6
1957	0.5	4.1	10.2	12.8	11.3	4.5	
1958	4.3	8.7	12.2	14.3	11.7	6.3	3.7
1959		7.9	13.5	13.2	12.2	7.1	3.8
1960		9.1	13.1	10.4	9.6	5.2	3.2
1961	2.6	5.0	10.7	15.9	10.6	7.1	4.3
1962	2.4		10.1	13.2	11.6	9.1	3.5
1963		8.5	11.7	10.6	9.3		4.1
1964	4.5		15.2	13.4	9.2	2.7	2.8
1965		6.8	13.0		10.5		2.2
1966	3.1	6.4	11.1	13.0	11.2	5.7	2.4
1967		7.4	13.0	14.1	11.2	7.2	3.2
1968		9.5			11.6	9.3	4.2
1969	2.6	8.4	11.1		9.8	6.2	4.5
1970	3.0	7.6	12.1		11.1	9.2	5.5
1971	4.5	6.4	6.5	6.7		9.1	2.2
1972	2.0	7.8	7.6		7.2	9.9	1.7
1973	2.9	6.8	8.9	13.3	6.9	6.6	0.8
1974	2.1	5.8	9.8	14.2	8.9		1.8
1975							
1976		9.3		13.2	10.6		
1977					7.6		

MAGDALEN SHALLOWS 0-10 m TEMPERATURE (BATHYTHERMOGRAPH) (°C)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1944					14.7	9.0	5.7
1945						11.3	
1946							
1947			16.3	17.5	14.1		5.7
1948	2.0	6.1	14.3			10.7	
1949		6.9	16.3	16.3		11.7	5.0
1950	5.5	9.4	14.5	19.3	15.0	9.0	5.1
1951		10.5	15.4	18.5	13.6		4.9
1952	3.1	9.3		18.2	16.6	9.4	
1953	3.3	6.9	13.8	16.2	14.0	9.1	5.8
1954	4.0	7.9	14.1			9.1	
1955	3.8	10.7	16.1	16.9			
1956	2.2	6.8	13.5	16.1	9.8		5.6
1957	2.7	7.5	14.9	13.6	12.5	7.7	7.9
1958	4.5	9.2	12.6	15.2	12.7	6.7	4.1
1959	3.0	7.5	12.6	15.3	13.4	10.1	5.6
1960	4.5	10.1		15.2	13.9	7.9	6.1
1961	2.1	7.9	14.4	15.2	15.2	10.6	6.1
1962	2.7	7.2	11.6	15.5		10.3	6.7
1963		7.7	14.1	14.8	12.3	11.3	6.6
1964	3.9	7.4	15.5	16.2	10.5		4.2
1965	1.4	7.2	15.5	16.8	13.0		3.8
1966	3.3	9.2	14.8	17.0	13.5		5.3
1967	-0.2	7.2	17.3	17.9	12.4	10.4	5.4
1968	3.5	9.0	12.8	14.8	11.7	9.8	5.6
1969	3.0	9.1	16.0	16.5	13.9	11.8	6.6
1970	4.3	9.7	15.4	18.1	12.3	12.8	6.0
1971	4.2		14.5	16.4	13.6		
1972	1.7	6.9	14.9	16.6	13.3		3.6
1973	1.8	6.6	13.9	18.1	14.0	9.1	5.3
1974	1.5			16.5	13.7		2.3
1975	2.9	6.6		17.1	13.4	7.2	
1976		6.8	13.2		13.3	7.5	
1977	2.7			17.0			

GRAHAM RIVER SURFACE TEMPERATURE (°C)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1944	3.6	8.5	14.0	14.5	13.2	7.6	4.2
1945	3.8	8.8	13.8	14.1	11.8	7.3	
1946	3.4	8.4	10.8	14.0			
1947	2.2	7.7	14.0	14.3	10.8		
1948	3.8	8.1	13.9	14.8	12.6		
1949	4.8	9.0	14.0	14.6	10.4		
1950	4.9	8.6	10.7	13.6	11.5		
1951	4.6	9.7	13.2	15.2	12.6	7.2	3.2
1952	4.2	9.0	14.9	14.1	12.3	6.8	
1953	5.0	8.9	13.1	13.3	10.6	7.2	4.6
1954	4.4	9.5	12.6	12.0	11.3	7.3	3.8
1955	5.3	9.8	15.6	15.1	11.9	7.3	4.6
1956	3.2	7.9	12.1	12.9	10.7	6.7	4.0
1957	3.8	8.7	10.7	14.2	11.0	7.1	4.6
1958	4.7	7.8	12.6	13.5	10.6	7.1	3.8
1959	4.3	7.9	13.5	14.6	12.7	8.0	3.6
1960	4.6	10.3	13.0	12.6	10.5	6.7	3.7
1961	3.8	8.1	12.7	13.7	11.2	8.6	4.9
1962	3.9	9.1	10.7	13.2	11.3	8.5	6.1
1963	3.9	9.3	13.1	14.2	10.9	7.5	4.4
1964	4.3	8.6	12.6	12.8	10.8	7.0	2.7
1965	3.6	8.3	12.3	13.0	10.6	6.0	2.3
1966	3.7	8.9	11.8	13.1	11.2	6.5	3.6
1967	2.9	9.2	14.7	16.5	12.1	7.7	6.6
1968	6.5	10.6	16.6	15.1	11.1	8.8	5.0
1969	3.7	8.6	12.7	14.7	11.2	7.6	4.9
1970	5.3	9.2	14.6	14.1	10.3	6.8	3.3
1971	5.1	9.6	13.5	13.8	10.8	6.5	3.2
1972	3.6	8.2	13.2	13.1	10.3	5.7	2.5

ENTRY ISLAND SURFACE TEMPERATURE (°C)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1944	5.3	10.0	15.2	17.0	14.6	9.5	5.3
1945	4.5	9.1	14.8	18.7	15.6	9.9	4.5
1946	3.5	8.8	14.4	17.2	15.7	11.9	5.5
1947		8.6	16.2	18.3	15.6	10.1	5.5
1948	3.7	8.3	14.0	17.0	14.0	10.1	6.4
1949	5.7	10.8	15.7	16.8	14.0	10.2	6.1
1950	5.1	10.2	14.9	17.3	14.3	9.0	5.8
1951	6.0	11.6	15.8	17.6		10.4	5.5
1952	5.6	9.9	15.6	18.3	15.7	10.3	4.4
1953	6.6	9.8	15.3	16.1	14.8	9.4	5.6
1954	5.4	9.9	15.1	15.1	13.3	9.3	4.8
1955	5.5	9.5	14.7	17.2	14.0	9.8	5.5
1956	5.2	9.5	15.1	16.5	14.6	9.7	5.6
1957	5.0	10.7	14.9	16.3	14.6	9.8	
1958	6.7	10.5	14.9	16.7	14.2	9.4	
1959	6.3	9.4	14.2	17.3	14.7	9.9	5.8
1960	7.4	12.2	17.3	18.4	14.8	9.3	5.3
1961	2.4	7.5	14.2	17.5	15.8	11.8	7.0
1962	5.0	9.0	13.3	15.5	13.7	10.0	5.4
1963	4.5	10.5			12.8	9.8	
1964	4.9	9.4	14.5	16.1	13.9	9.7	3.8
1965	5.0	9.4	15.1	17.2	13.7	8.6	3.2
1966	5.5	11.1	14.8	18.2	14.2	9.5	5.9
1967	2.2	9.5	16.0	19.5	15.0	10.3	5.9
1968	6.8	11.1	15.7	16.2	15.7	11.9	5.2
1969	5.9	11.2	13.4	18.0	14.9	9.6	6.6
1970	6.5	10.9	16.0	19.0	12.8	10.7	6.5
1971	6.1	10.7	15.5	17.5	14.7	10.1	5.0
1972	2.8	9.2	15.5	16.3	13.9	8.6	3.8
1973	2.1	9.5	16.4	18.3	15.0	9.2	3.4
1974	4.6	10.3	14.1	17.8	14.4	8.2	4.2
1975	4.4	10.1			15.4	9.3	
1976	6.3	10.4	14.8	16.7	14.8		
1977	4.7	9.6	10.8	17.6	14.6	10.2	6.0

CHARACTERISTICS OF INTERMEDIATE COLD LAYER

1 DEPTH UPPER 1.5C ISOTHERM (M) INTERP. TO JULY 15
2 DEPTH LOWER 1.5C ISOTHERM (M) NO INTERP.
3 THICKNESS OF TEMPERATURE MIN. LAYER (M) (JULY 15)
4 DEPTH TEMPERATURE MINIMUM (CORE DEPTH) (M) INTERP. TO JULY 15
5 TEMPERATURE OF TEMPERATURE MIN (C) INTERP. TO JULY 15

1951	41.0	143.4	102.4	76.9	0.51
1952	33.1	116.4	83.3	67.0	-0.01
1953	37.7	103.4	65.7	57.4	0.22
1954	48.7	116.6	67.9	68.3	0.25
1955	39.9	136.1	96.2	67.1	-0.03
1956	31.1	134.2	102.6	74.9	-0.18
1957	40.0	147.5	107.5	85.1	-0.20
1958	54.0	142.3	88.3	82.9	0.50
1959	43.8	126.6	82.8	70.4	-0.39
1960	27.8	143.5	115.7	71.8	-0.31
1961	32.3	145.0	112.7	64.2	-0.81
1962	33.3	147.2	113.9	66.7	-0.44
1963	32.8	144.2	111.4	60.0	-0.32
1964	28.9	138.8	109.9	57.8	-0.23
1965	30.8	146.1	115.3	70.2	-0.14
1966	45.1	144.1	99.0	87.4	-0.09
1967	24.1	134.2	110.1	58.3	-0.06
1968	37.3	116.4	79.1	59.6	-0.04
1969	49.4	114.1	64.9	72.8	0.77
1970	39.6	82.3	42.7	58.7	1.10
1971	30.0	93.4	63.4	49.4	0.37
1972	24.9	119.2	94.3	52.7	-0.69
1973	30.3	128.5	98.2	52.7	-0.20
1974	26.1	118.3	92.2	57.7	-0.37
1975	38.0	150.5	112.5	67.9	-0.62

NORTHWEST GULF (0-10m) SALINITY (°/..)

1 N-W GULF - MAY
2 N-W GULF - JUNE
3 N-W GULF - JULY
4 N-W GULF - AUGUST
5 N-W GULF - SEPTEMBER
6 N-W GULF - OCTOBER
7 N-W GULF - NOVEMBER

1944							
1945							
1946				28.0	30.0	30.6	
1947	29.6	28.9			29.4		30.4
1948		29.5				30.2	
1949							31.1
1950		29.0			29.4	30.1	
1951					29.9		
1952	29.8	29.0		27.7	28.5	29.5	
1953		28.7	28.6	30.0	29.5	30.6	
1954				29.9		30.0	
1955				29.1			
1956	30.9	28.5	27.2	29.7	28.6		30.4
1957		29.7	29.3	30.0			
1958							
1959			29.6	28.8	30.0	30.3	
1960		28.5			29.8		
1961	29.1	29.9	28.6			30.2	30.1
1962	30.2		29.3	29.8	29.9	29.7	30.9
1963		29.1	28.3	28.9	30.3		30.6
1964				29.1	31.0		30.9
1965		30.3			29.2	28.4	30.9
1966	31.6	30.7			29.7		30.9
1967		29.4		29.7	29.3		30.8
1968	29.5	29.1			30.2		30.7
1969	30.6	27.5	28.0	29.5	29.6	28.4	30.1
1970	30.8	28.4	28.6	29.2	29.8		
1971	28.3		29.4	28.8	29.4	30.5	30.6
1972				29.2	29.7		30.0
1973					28.5		
1974					29.0		
1975					29.1		
1976					28.9		
1977							

MAGDALEN SHALLOWS (0-10m) SALINITY (°/..)

1 MAY
2 JUNE
3 JULY
4 AUGUST
5 SEPTEMBER
6 OCTOBER
7 NOVEMBER

1945				27.4		29.0	28.7
1946	30.8		28.8	28.9	29.6	29.5	
1947	31.4	30.2	28.0	27.4	27.6	28.7	29.8
1948	31.2	30.4	29.5	28.7	28.8	29.5	29.3
1949	30.4	29.8	28.7	28.2	28.5	28.9	29.8
1950	31.6		30.9		29.4	29.9	
1951					28.8	27.9	30.0
1952	30.3	28.9		28.0	27.2	29.1	
1953		28.5	27.8	27.5	29.1	29.7	30.3
1954	31.3	27.9	27.5	28.9		29.5	
1955		30.1	28.0	28.6			29.8
1956	31.2	29.1		29.1	29.2	29.3	30.2
1957	31.6	30.4		28.4			
1958	30.2	28.4					
1959			29.3	28.6	29.9	29.9	31.1
1960	31.1	28.4		28.6	29.4		
1961	30.3	28.5	28.7	27.9	28.1	29.8	30.3
1962	31.7	30.7	27.8	238.7		30.4	30.4
1963		30.3	27.6	29.6	29.6	29.8	30.5
1964			28.6	30.0	29.8		31.2
1965	32.0	30.6	29.5	29.9	30.3		31.0
1966	31.0	29.9	29.3	29.3	29.7		30.5
1967		28.6		28.6	29.3		30.3
1968	31.3	30.2		29.8	30.3		31.0
1969	30.0	29.9	28.5	28.9	29.2		29.6
1970	30.3	30.3	29.1	28.0	29.6		
1971	29.8	29.3	31.2	28.3	29.2		30.6
1972	29.9			28.2	29.1		29.9
1973	30.2				28.5		
1974	31.7			28.1	29.0		
1975	30.8				29.6		
1976					28.9		

GULF RIVSUM-ANNUAL AND MONTHLY MEAN (THOUSANDS OF CUBIC FT/SEC)

1 JANUARY
2 FEBRUARY
3 MARCH
4 APRIL
5 MAY
6 JUNE
7 JULY
8 AUGUST
9 SEPTEMBER
10 OCTOBER
11 NOVEMBER
12 DECEMBER
13 ANNUAL MEAN

1940	257.0	255.0	252.0	325.0	462.0	503.0	378.0	317.0	310.0	289.0	287.0	286.0	326.7
1941	288.0	276.0	280.0	392.0	379.0	317.0	295.0	286.0	316.0	350.0	354.0	310.0	320.4
1942	293.0	285.0	319.0	398.0	514.0	401.0	330.0	316.0	305.0	325.0	344.0	299.0	344.0
1943	288.0	301.0	318.0	394.0	574.0	529.0	399.0	371.0	366.0	345.0	348.0	336.0	380.7
1944	318.0	306.0	315.0	340.0	397.0	367.0	337.0	325.0	320.0	318.0	309.0	301.0	329.3
1945	270.0	282.0	349.0	447.0	478.0	442.0	379.0	342.0	355.0	388.0	367.0	344.0	370.3
1946	345.0	328.0	377.0	401.0	442.0	427.0	372.0	336.0	322.0	333.0	339.0	336.0	363.1
1947	331.0	340.0	343.0	460.0	624.0	693.0	445.0	385.0	374.0	362.0	341.0	336.0	419.4
1948	307.0	301.0	347.0	425.0	454.0	398.0	366.0	355.0	339.0	326.0	316.0	306.0	353.3
1949	309.0	316.0	345.0	311.0	458.0	426.0	355.0	318.0	313.0	310.0	292.0	298.0	377.6
1950	319.0	322.0	326.0	407.0	436.0	456.0	388.0	343.0	329.0	323.0	332.0	343.0	360.3
1951	348.0	334.0	390.0	596.0	527.0	408.0	409.0	374.0	362.0	369.0	409.0	392.0	409.7
1952	384.0	388.0	399.0	494.0	520.0	479.0	406.0	395.0	375.0	369.0	351.0	368.0	410.6
1953	366.0	375.0	410.0	500.0	468.0	384.0	367.0	350.0	336.0	325.0	314.0	320.0	376.3
1954	310.0	319.0	371.0	458.0	473.0	436.0	385.0	356.0	351.0	398.0	397.0	387.0	386.8
1955	381.0	357.0	387.0	521.0	487.0	398.0	362.0	343.0	333.0	337.0	380.0	353.0	386.5
1956	324.0	316.0	319.0	401.0	444.0	436.0	398.0	385.0	401.0	389.0	352.0	346.0	375.8
1957	338.0	335.0	340.0	356.0	364.0	372.0	434.0	333.0	354.0	343.0	370.0	357.0	357.8
1958	353.0	340.0	359.0	400.0	370.0	396.0	356.0	317.0	346.0	335.0	327.0	320.0	351.4
1959	277.0	290.0	299.0	411.0	451.0	398.0	345.0	320.0	313.0	306.0	334.0	339.0	340.3
1960	324.0	330.0	335.0	462.0	606.0	431.0	421.0	416.0	333.0	294.0	312.0	299.0	380.2
1961	300.0	302.0	296.0	347.0	398.0	398.0	372.0	358.0	353.0	326.0	299.0	311.0	338.2
1962	306.0	308.0	300.0	350.0	367.0	334.0	293.0	302.0	293.0	289.0	287.0	279.0	308.9
1963	276.0	274.0	269.0	343.0	333.0	316.0	304.0	291.0	284.0	282.0	288.0	299.0	296.5

GULF RIVSUM-ANNUAL AND MONTHLY MEAN (THOUSANDS OF CUBIC FT/SEC) - cont'd

1965	270.0	265.0	272.0	296.0	333.0	299.0	284.0	326.0	332.0	289.0	351.0	353.0	314.0
1966	339.0	334.0	364.0	396.0	376.0	363.0	306.0	327.0	316.0	361.0	361.0	393.0	353.0
1967	348.0	358.0	318.0	399.0	422.0	389.0	343.0	323.0	312.0	407.0	472.0	408.0	374.9
1968	359.0	362.0	353.0	434.0	370.0	339.0	348.0	350.0	364.0	347.0	342.0	338.0	358.7
1969	325.0	347.0	354.0	420.0	467.0	456.0	404.0	396.0	362.0	338.0	385.0	355.0	384.1
1970	327.0	333.0	334.0	383.0	459.0	430.0	416.0	388.0	363.0	360.0	359.0	351.0	375.4
1971	324.0	335.0	357.0	433.0	485.0	379.0	338.0	331.0	338.0	354.0	322.0	315.0	359.2
1972	306.0	316.0	338.0	419.0	516.0	449.0	433.0	424.0	416.0	420.0	422.0	374.0	402.6
1973	358.0	389.0	465.0	516.0	583.0	521.0	477.0	443.0	415.0	426.0	396.0	371.0	446.7
1974	343.0	367.0	430.0	484.0	653.0	624.0	463.0	424.0	398.0	397.0	402.0	395.0	448.3
1975	368.0	356.0	403.0	433.0	479.0	444.0	370.0	359.0	357.0	364.0	371.0	357.0	388.4
1976	339.0	355.0	417.0	567.0	654.0	505.0	454.0	415.0	395.0	403.0	377.0	319.0	433.3
1977	307.0	296.0	380.0	456.0	483.0	366.0	333.0	342.0	367.0	390.0	395.0	370.0	373.8
1978	364.0	399.0	391.0	439.0	495.0	455.0	383.0	361.0	348.0	355.0	338.0	308.0	386.3
1979	312.0	339.0	397.0	492.0	516.0	474.0	379.0	381.0	389.0	430.0	434.0	438.0	415.1

LOBSTER LARVE-NORTHUMBERLAND STRAIT (NUMBER PER 3430 m^2)

1 STAGE 1 ($x10^{-1}$)
2 STAGE 2
3 STAGE 3
4 STAGE 4
5 1-4 PERCENT SURVIVAL (X10)

1949	72.0	63.1	17.1	1.6	2.2
1950	105.2	158.4	55.0	6.6	6.2
1951	55.1	77.8	23.6	7.3	13.2
1952	139.4	234.1	75.8	34.8	24.9
1953	69.9	77.6	14.5	5.7	8.1
1954	52.9	47.7	7.1	0.9	1.7
1955	109.1	143.1	30.1	8.7	7.9
1956	82.6	111.2	41.1	19.8	23.9
1957	89.9	200.3	47.9	16.2	17.9
1958	45.7	61.5	24.5	5.7	12.4
1959	33.4	48.2	5.7	1.6	4.7
1960	51.9	41.4	6.6	0.8	1.5
1961	75.9	182.8	7.5	1.2	1.5
1962	30.9	23.4	5.0	0.3	1.1
1963	69.6	56.1	8.9	0.9	1.3

LOBSTER LANDINGS GULF OF ST. LAWRENCE (lbs year^{-1})

1 CHALEUR BAY X^{-4}
2 NOTHUMBERLAND-KENT $x10^{-4}$
3 CENTRAL STRAIT X 10^{-4}
4 SOUTH STRAIT X 10^{-4}
5 NORTH INVERNESS $x10^{-4}$
6 MACDALEN ISLANDS $x10^{-4}$
7 NEWFOUNDLAND $x10^{-4}$
8 RIVSUM -9 YR LAG
9 PEI-STRAIT $x10^{-4}$
10 PEI-GULF $x10^{-4}$
11 NFDL-NORTH GULF $x10^{-4}$
12 NFDL-SOUTH GULF $x10^{-4}$
13 NFDL-ATLANTIC COAST $x10^{-4}$

1940	61.1	126.1	103.6			78.6	121.6	302.3					
1941	57.2	123.4	98.8			79.6	107.9	363.4					
1942	71.5	137.5	117.1			71.7	96.9	315.3					
1943	72.2	141.8	100.5			75.8	86.2	304.3					
1944	75.2	165.7	94.1			102.6	104.0	292.1					
1945	96.0	164.6	77.9			108.7	145.9	330.8					
1946	118.5	175.8	115.5			104.3	126.6	346.2					
1947	93.0	131.6	96.4	102.7	16.3	72.8	154.5	347.9					
1948	97.0	162.5	104.0	137.5	21.6	98.6	168.6	334.9					
1949	92.1	199.8	131.7	144.7	21.6	83.9	228.6	326.7					
1950	123.8	239.0	152.4	165.1	22.9	90.6	229.5	320.4					
1951	98.7	214.9	164.6	155.7	45.0	97.1	196.0	344.0					
1952	91.6	210.2	144.1	177.8	23.3	97.3	168.9	380.7					
1953	82.4	169.4	105.5	150.8	38.2	109.7	203.1	329.3			70.0	45.3	68.0
1954	86.7	144.2	123.7	178.4	32.0	112.6	237.8	370.3			61.0	44.1	81.4
1955	68.1	162.0	190.5	190.4	26.4	115.5	249.9	363.1			106.1	59.0	85.3
1956	131.3	200.6	207.5	174.5	20.7	146.7	218.8	419.4			111.6	39.8	67.9
1957	120.0	174.9	222.6	144.7	18.9	115.3	190.4	353.3	175.0	212.1	97.6	32.8	60.3
1958	93.5	162.4	199.4	130.8	21.4	108.5	213.0	337.6	184.1	177.3	94.3	40.7	78.5
1959	95.0	176.8	194.1	160.1	32.0	127.2	169.9	360.3	206.5	174.3	75.0	29.6	65.7
1960	107.5	209.0	256.7	158.3	29.0	152.8	204.5	409.7	247.4	212.4	83.9	39.0	82.1
1961	114.5	150.0	253.9	144.2	28.4	137.1	177.8	410.6	212.9	218.5	66.6	32.7	78.9
1962	107.8	126.1	230.6	126.2	28.4	176.8	188.4	376.3	191.7	203.4	78.8	31.1	78.9
1963	84.3	125.5	180.9	118.7	26.2	160.8	203.8	386.8	159.4	175.6	93.4	29.5	81.4
1964	83.3	125.6	134.3	118.6	24.9	126.6	204.6	386.5	162.6	192.3	86.7	34.4	84.0

LOBSTER LANDINGS GULF OF ST. LAWRENCE (lbs year^{-1}) - cont'd

1965	82.7	114.1	88.5	125.4	28.4	131.5	169.5	375.8	166.1	234.7	81.5	28.1	60.3
1966	88.7	126.3	61.6	95.1	29.1	150.0	158.0	357.8	134.4	221.7	69.1	24.6	64.7
1967	79.1	108.2	40.9	95.7	31.1	128.5	141.4	351.4	135.7	270.8	75.8	16.0	50.0
1968	76.8	133.8	53.7	107.6	28.6	105.9	180.8	340.3	184.1	240.5	101.0	14.3	65.7
1969	65.2	113.6	52.9	95.9	25.1	88.3	170.3	380.2	164.5	235.5	99.0	16.7	57.6
1970	79.2	119.5	53.0	89.2	30.1	98.6	146.0	338.2	161.8	270.9	88.5	14.4	43.7
1971	65.5	109.4	64.9	89.5	29.1	93.2	138.1	308.9	177.5	213.4	89.4	15.5	33.3
1972	72.0	112.1	43.4	84.4	32.8	78.0	123.7	296.5	140.3	209.5	75.9	18.1	30.1
1973	62.3	112.7	35.7	81.9	27.0	90.8	126.3	303.2	150.7	225.6	70.4	26.9	29.3
1974	64.8	99.2	39.1	55.3	22.7	86.2	132.6	314.0	113.8	170.2	70.7	37.6	24.4
1975	93.7	145.3	46.7	88.1	24.5	98.4	169.7	353.0	163.9	237.8	71.2	51.4	44.0
1976	99.5	129.7	49.0	72.5	25.2	99.8	222.9	374.9	148.1	238.9	95.6	75.1	55.2
1977	100.4	141.9	74.4	76.9	25.8	115.7	218.0	358.7	175.8	257.3	78.2	70.0	61.9
1978	143.9	173.2	95.4	104.6	31.5	109.1	247.1	384.1	201.5	284.3	92.4	73.6	81.6
1979	148.3	191.7	79.1	133.2	35.1	259.2			231.4	336.3	87.5	92.3	79.9

GULF FINFISH BIOMASS INDICES

1 4T-4VN CODD RECRUITMENT (AGE-3) 10^6 INDIVIDUALS
2 S. GULF HERRING RECRUITMENT (AGE-2) 10^7 INDIVIDUALS
3 3-6 MACKEREL RECRUITMENT (AGE-1) 10^7 INDIVIDUALS
4 3PN-4RS COD CATCH/UNIT EFFORT (T/HRX10)
5 4RST REDFISH CATCH/UNIT EFFORT (T/HXR10)
6 4T-4VN COD 3+BIOMASS (X10-4T) (COHORT ANALYSIS)
7 4T-4VN COD FISHABLE BIOMASS (X10-4T) (COCHORT ANALYSIS)
8 3-6 MACKEREL STOCK BIOMASS (X10-4T) (COHORT ANALYSIS)
9 S. GULF COD-MEAN LENGTH (CM) ATEND OF FIRST YR
10 S. GULF COD (4 T) INSTANTANEOUS GROWTH DURING FIRST YR

	1	2	3	4	5	6	7	8	9	10
1947	114.0									
1948	109.6									
1949	113.5									
1950	108.5									
1951	78.8					32.5			6.39	
1952	70.0					35.6			6.07	
1953	83.9					37.8			6.78	
1954	106.7				12.3	38.0			7.24	
1955	110.5				12.4	34.1			7.35	
1956	143.4				8.6	31.0			7.18	
1957	134.5				6.9	29.0			7.08	
1958	45.9				6.2	30.0			7.55	0.043
1959	59.8			15.1	5.6	29.5			7.37	0.091
1960	41.3			13.2	5.6	31.9			6.36	0.077
1961	60.4		86.1	17.4	5.4	34.7			6.31	0.05
1962	52.2		47.1	15.8	4.0	28.6		99.8	6.04	0.049
1963	61.4	195.9	51.2	20.4	7.7	25.8		90.5	6.10	0.083
1964	105.7	93.3	55.1	19.5	8.6	20.1		88.1	5.87	0.083
1965	93.6	89.3	119.4	17.3	9.7	18.0		86.8	5.76	0.121
1966	57.4	68.5	332.6	16.1	11.5	15.0		94.9	6.24	0.106
1967	51.6	69.5	779.1	13.2	12.8	14.3	17.11	11.8	6.67	0.087
1968	77.1	79.4	314.6	16.2	12.1	18.9	17.52	40.3	8.31	0.138
1969	30.5	27.0	317.6	14.5	8.1	21.3	18.82	59.4	8.11	0.072
1970	47.9	57.3	172.3	14.2	7.1	19.8	20.72	30.4	8.07	0.102
1971	61.9	24.9	174.6	10.8	6.4	16.9	19.92	19.4		0.052